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Project Technical Guidelines

Technical Support Services for Ohio Air Quality Development Authority (OAQDA)

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EXECUTIVE SUMMARY

These Technical Guidelines provide detailed information that supplements the OAQDA Project Development and Financing Program Guidelines. The Technical Guidelines provide an Overview to the Application Review and eight separate analysis guidelines for the measurement and verification of:

- Whole-building,
- Component Isolation - new construction,
- Component Isolation – retrofit,
- Component Isolation – renewable projects,
- Component Isolation – Criteria Pollutant (new project),
- Component Isolation – Criteria Pollutant (retrofit),
- Before-After Analysis (12 month operation), and
- Before-After Analysis (K-12 Schools & Universities).
- Costing Information

In addition to these sections a Review of ASHRAE's Inverse Model Toolkit is provided, and a section that provides costing information, as well as a Glossary and references. The material in this Technical Guideline and the referenced work are intended to be guide for use by applicants as they prepare their projects for successful approval and measurement and verification by the OAQDA.

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1.0 TECHNICAL GUIDELINES

1.1 OVERVIEW

The Technical Guidelines for the Program are meant to provide a framework that will be used for the technical review and evaluation of applications, including any technical requirements that need to be met by the applicant during the process. The process involves several stages that are aligned with the typical development of projects and are intended to leverage existing information that may be produced for the successful design, construction, commissioning and operation of projects. All interested parties are encouraged to contact OAQDA regarding their project to identify the best course of action for application submission.

A. Application Submission

In general, the application submission must provide sufficient information for OAQDA to determine if the project qualifies. To accomplish this, the project must contribute to improved air quality to be deemed an air quality facility by OAQDA and meet the Program guidelines outlined herein. Currently, these guidelines include the following project types: whole-building projects; and component isolation projects (new construction, retrofit, renewable energy generation, criteria pollutant/greenhouse gas reduction). For all projects except criteria pollutant reduction projects, applicants should compare estimated energy savings to those published in the 2020 State of Ohio Technical Reference Manuals where appropriate (Ohio 2020 a, b, c, d).

B. Project Review

The project review process for a project begins with a code-compliance review of the proposed project to ensure that the project is more stringent than the current building code, federal equipment standards or applicable rules for pollution control. Once a project successfully completes this stage of the review there is a review of the metering plan, construction plan, and commissioning plan. Successful completion of all these plans is then followed by the project construction and project commissioning report. Satisfactory review of the construction and commissioning reports is then followed by an occupancy permit. Once the occupancy or applicable permit is issued, the metered data collection begins.

C. Minimum Thresholds

All project applications should address the following minimum thresholds, including: Minimum Building Energy Code; Federal Equipment Standards; Criteria Pollutant Cost Savings and Greenhouse Gas Cost Savings.

1) <u>*Minimum Building Energy Codes.*</u> All whole-building projects and component isolation projects (new or retrofit) shall be designed and

constructed to exceed the energy efficiency standards adopted by the Ohio Board of Building Standards in rules 4101:1-13-01 and 4101:1-35-01 of the Ohio Administrative Code.

2) *Federal Energy Efficiency Standards.* All new equipment installed in whole-building energy efficiency and component isolation projects (new or retrofit) shall be selected, designed and constructed in accordance with Federal Energy Efficiency Standards 10 CFR 433.100 and any subsequent amendments.

3) *Ohio's Technical Resource Manual.* For all projects except criteria pollutant reduction projects, applicants should compare estimated energy savings to those published in the 2020 State of Ohio Technical Reference Manuals where appropriate (Ohio 2020a,b,c,d).

4) *Criteria Pollutant and Greenhouse Gas Cost Savings.* All projects that provide criteria/GHG pollutant savings shall meet or exceed any applicable federal or state air pollution rule of regulation. Because these rules can be complex, it is recommended the applicant verify which rules are applicable by contacting either the Ohio EPA or by utilizing an experienced air pollution consultant.

   OAQDA will routinely research and evaluate the effectiveness of projects to reduce harmful air pollutants and greenhouse gases in Ohio. As part of this effort, OAQDA will use the level of tax exemption incentive amounts projected for each project application and benchmark it with available industry data as well as the total performance of projects previously approved by OAQDA. This information will be developed by OAQDA as part of the application process and presented to the OAQDA Board.

D. Measurement & Verification (M&V)

The measurement and verification process for projects consists of three stages and will be implemented alongside the review of other steps in the project evaluation process as described herein. These steps may include: (1) the Application Submittal and Review stage; (2) the M&V Plan Submittal and Review stage; and, (3) the Project M&V Process stage. All projects need to comply with each stage in sequence to qualify as an Air Quality Control facility. Applicable projects include: whole-building projects; component isolation projects (new construction, retrofit, renewable energy generation, criteria pollutant/greenhouse gas reduction).

1) *Application Submittal and Review.* In general, the application and review process for a project begins with a code-compliance review of the proposed project to ensure that the project is more stringent than the current building code and federal equipment efficiency standards. In the case of criteria pollutant or greenhouse gas savings projects, the application must demonstrate adherence to or exceedance of the applicable air pollution rule of regulation. Once a project successfully completes this stage of the review it is followed by a review of the metering plan, construction plan, and

commissioning plan.

2) *M&V Plan Submittal and Review*. In this section of the process the M&V Plan is submitted by the applicant and reviewed by OAQDA. The review of the M&V Plan precedes the construction of the project because it is necessary to ascertain if and where meters are to be placed in the building (or project), or if whole-building gas and/or electric meters are appropriate for measuring savings, and what energy end-use quantities are to be measured before construction begins. In addition, these energy end-use measurements must align with the simulated energy end-use quantities so the simulation can be used to assist in the project verification process. In addition, adherence to the recommendations in ASHRAE Guideline 14-2014 (ASHRAE 2014, including July 2019 errata) and/or the Uniform Performance Measurement (UMP) guidelines (UMP 2020) is important to ensure accurate measurement and reporting.

   For the criteria pollutant and greenhouse gas savings projects, OAQDA will work with the applicants on appropriate M&V plans based on the type of pollutant, technology, applicable rules of regulation and any involvement of state or local air pollution control agencies. In most cases, OAQDA will coordinate with the Ohio Environmental Protection Agency (OEPA) on their similar monitoring efforts as it relates to projects involving air permits or other requirements under their purview.

   Project M&V Process. In this section of the process the Project M&V Process is monitored to determine that the data collection efforts are complying with the M&V Plan submitted by the applicant and reviewed by OAQDA. The review of the Project M&V Process begins before the retrofit or after the new construction is complete and proceeds throughout the project period. These measurements are necessary to ascertain that energy end-use quantities agree with design estimates to assist in the project verification process. In addition, adherence to the recommendations in ASHRAE Guideline 14-2014 (ASHRAE 2014, including 2019 errata) and/or the Uniform Performance Measurement (UMP) guidelines (UMP 2020) is important to ensure accurate measurement and reporting.

   For the criteria pollutant and greenhouse gas savings projects, OAQDA will coordinate with the Ohio EPA and local air pollution control agencies to utilize existing methods for monitoring and compliance related to permits for the same project as the method for the verification of project performance. If there is not an ability to coordinate with OEPA, then OAQDA will review the M&V process and reporting based on details described in the M&V plan for the specific pollutant, technology, and adherence to applicable rules of regulation.

E. Level of Improvement to Air Quality

The level of improvement to air quality depends on the assessment by OAQDA, which is described in the following table.

TYPE OF PROJECT	MEASUREMENT/ QUANTIFICATION	IMPROVEMENT TO AIR QUALITY	ENTITY PERFORMING CALCULATION
Whole-building	Energy Units: kWh, MCF, MMBtu	Calculated using standard conversions	Energy units calculated by applicant. Air Quality calculated by OAQDA
Component Isolation – new construction	Energy Units: kWh, MCF, MMBtu	Calculated using standard conversions	Energy units calculated by applicant. Air Quality calculated by OAQDA
Component Isolation – retrofit project	Energy Units: kWh, MCF, MMBtu	Calculated using standard conversions	Energy units calculated by applicant. Air Quality calculated by OAQDA
Component isolation – on-site renewable	Energy Units: kWh, MCF, MMBtu	Calculated using standard conversions	Energy units calculated by applicant. Air Quality calculated by OAQDA
Component isolation - criteria pollutant or greenhouse gas.	Pollution Units: lbs-NOx, lbs-SOx, lbs-CO2, lbs-PM	Measured continuously over project period.	Pollution units measured on-site.

Table 1: Level of Improvement to Air Quality.

1.2 APPLICATION REVIEW AND M&V GUIDELINE

This sub-task describes the process for the application review. Each of the steps in the process are shown in Figure 1 and described in the following section.

Application Submittal & Review: In this section of the process the base-case input and proposed input files are reviewed by OAQDA to determine if they are compliant with the current Energy Code for the State of Ohio. If it is determined that code compliance has not been accomplished in the input file of either the base-case input file or the proposed input file, then the input files are modified by the Applicant, the simulation rerun and re-reviewed until code-compliance is obtained. Once both files have been determined to be code compliant by OAQDA, then the

Applicant submits a Metering Plan for review by OAQDA. Electronic copies of the code-compliant base-case input file and code-compliant proposed input file are delivered to OAQDA in the appropriate machine-readable format for archival purposes.

M&V Plan Submittal and Review: In this section of the process the M&V Plan is submitted by the applicant and reviewed by OAQDA. The review of the M&V Plan precedes the construction of the project because it is necessary to ascertain where meters are to be placed in the building (or project) and what end-use energy use quantities are to be measured before construction begins. In addition, these end-use energy use measurements must align with the simulated end-use energy use quantities so the simulation can be used to assist in the project verification process.

M&V Process: Once the Metering Plan has been submitted and successfully reviewed by the OAQDA a Construction Plan is submitted by the Applicant and reviewed by the OAQDA. This Construction Plan must be carefully inspected to determine if there are issues during the construction process that make significant changes to the project configuration that require revisions to the energy savings estimates or to the Metering Plan. Once the Construction Plan is approved by the OAQDA then project the Applicant must submit a Commissioning Plan before construction can begin.

This Commissioning Plan details how the HVAC equipment are to be inspected during construction to determine that the actual installed equipment meets the design intent. The review of the Commissioning Plan also needs to determine if significant changes have occurred during this phase that would require a change to either the code-compliant, base-case simulation input file, or to the proposed simulation input file.

If it is determined during the review of the Commissioning Plan that significant changes have occurred to the project, and that these changes impact the energy savings estimates, then the OAQDA will need to determine whether any adjustments will need to be made to the estimated energy savings for the project and the associated emissions reductions. Once the Commissioning Report is approved by the OAQDA then an Occupancy Permit can be issued.

In the building occupancy period the collection of the metered data begins in accordance with the Metering Plan. The length of time needed for metering depends on the type of Energy Conservation Design Measures (ECDMs) that have been installed. For example, if the ECDMs impact the building's heating or cooling systems, then there will need to be data collected during the heating and/or cooling seasons (i.e., weather dependent period) to assure that an adequate analysis can be accomplished.

During this stage of the project it the Applicant will need to develop an as-built whole-building simulation input file or component simulation file that represents the actual equipment installed in the project. This as-built simulation file will need to be reviewed by the OAQDA to determine if any significant changes have occurred to the project that would necessitate a change to the overall project energy savings estimates.

This as-built simulation input file will then be archived at the OAQDA for diagnostic purposes (as well as the code-compliant simulation input file) should it be determined that the measured energy savings do not match the simulated energy savings for the project.

The as-built simulation input file will be used by OAQDA to generate hourly energy use data for the project during the time period when the building is occupied. This hourly energy use is created by running the whole-building simulation, or component simulation with the actual, hourly weather conditions measured near to the site. The simulated hourly energy use data are then analyzed with the ASHRAE Inverse Model Toolkit (Figure 2) to develop regression coefficients that represent the simulated energy use of the base-case building and as-built building. These coefficients can then be compared to regression coefficients generated using the measured energy use.

In a similar fashion, as the simulated hourly energy use, the ASHRAE Inverse Model Toolkit (IMT) is also used to analyze the measured whole-building metered data from the project once the building is constructed, commissioned and occupied. The IMT coefficients from the simulated energy use of the base case and proposed buildings are then compared to the IMT coefficients from the metered energy use to determine if the building's energy use matches the simulated energy use.

If the coefficients do not agree then the as-built hourly simulation model is run using measured weather data from the site and the results from the simulation model are examined to determine where the discrepancy is occurring (i.e., cooling, heating or weather independent loads) and the possible cause of the discrepancy (i.e., a mismatch in the performance specifications of the chiller, boiler, etc.). This process continues until the simulated energy use from the model agrees with the energy use from the metered data.

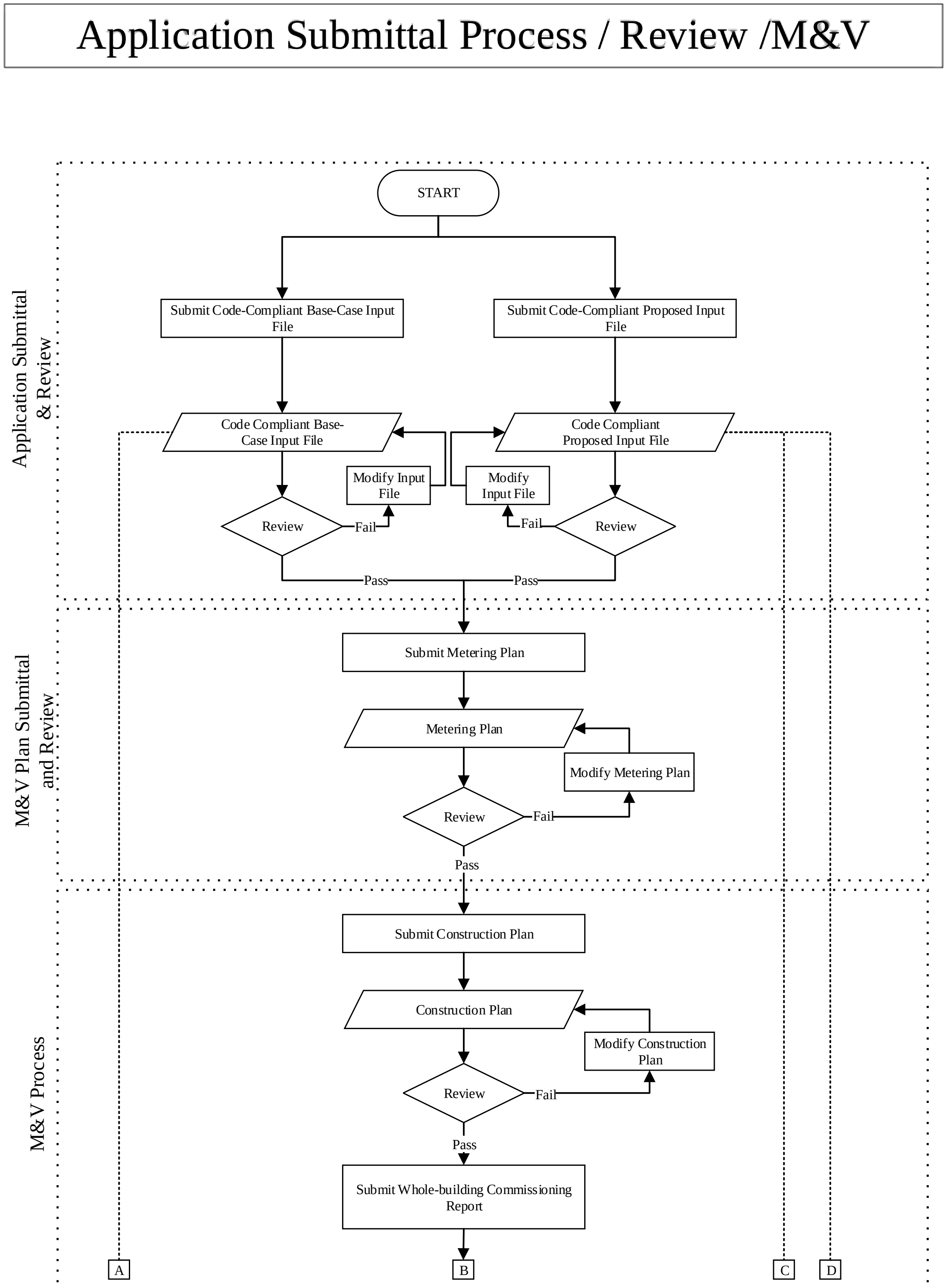


Figure 1: Application Submittal Process, Review and M&V

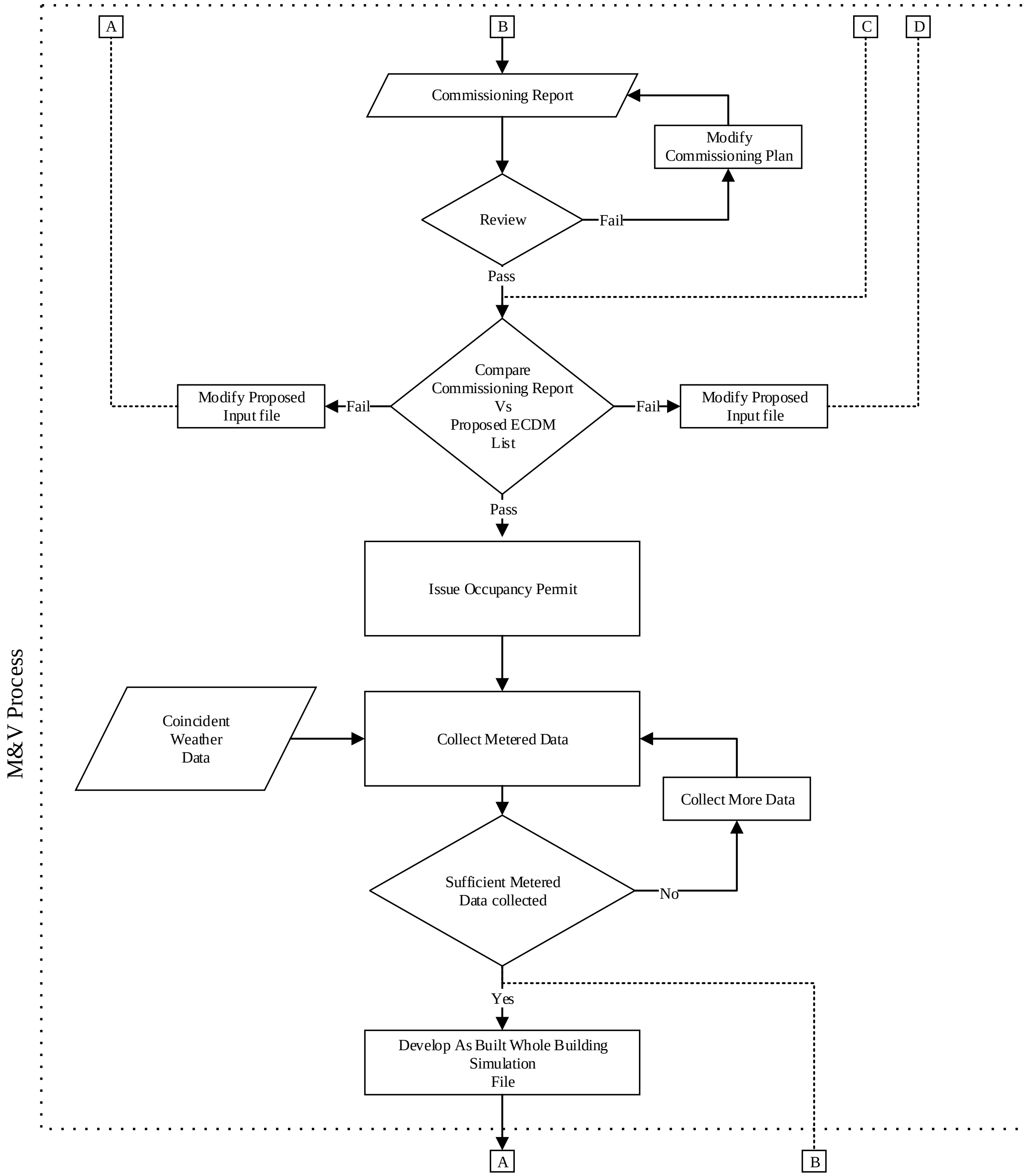


Figure 1: Application Submittal Process, Review and M&V (cont.)

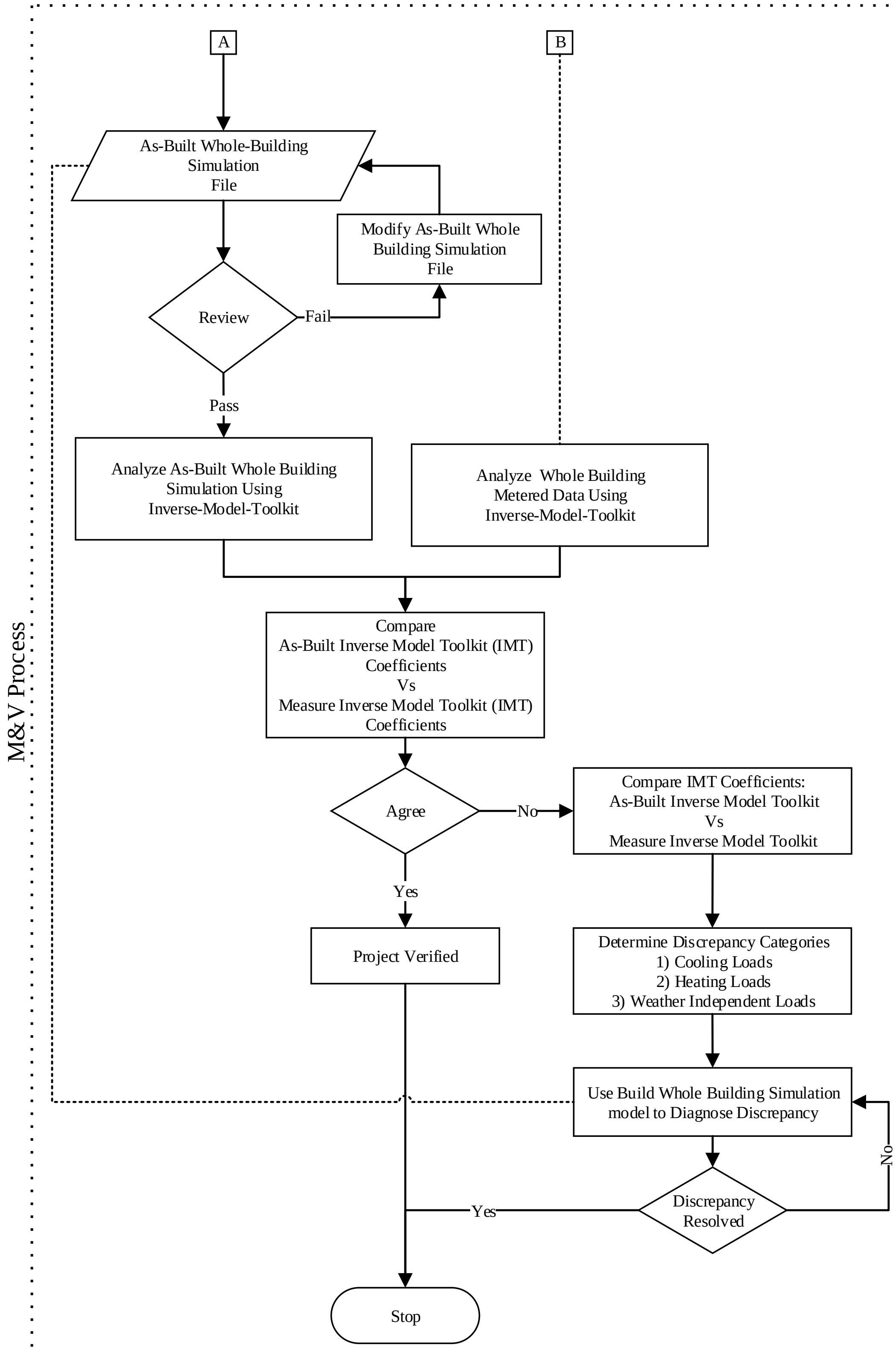
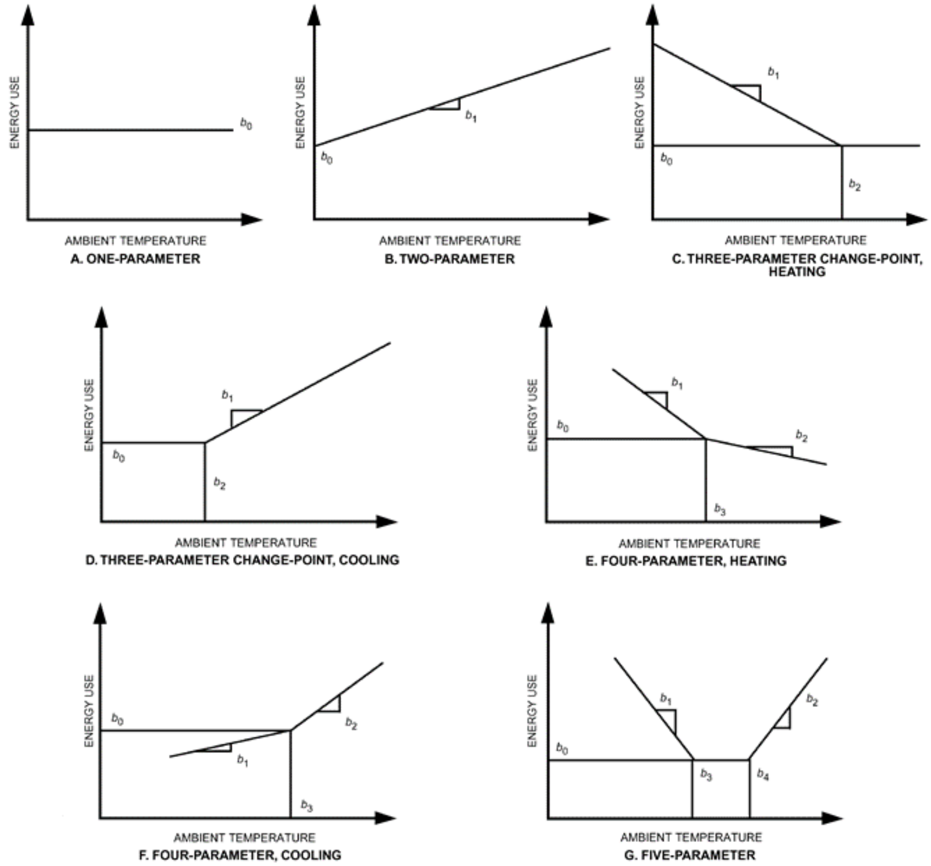


Figure 1: Application Submittal Process, Review and M&V (cont.)



Name	Independent Variables	Form	Examples
No adjustment/ constant model	None	$E = E_b$	Non-weather-sensitive demand.
Day-adjusted model	None	$E = E_b \times \text{day}_b/\text{day}_c$	Non-weather-sensitive use (fuel in summer, electricity in summer).
Two-parameter model	Temperature	$E = C + B_1(T)$	
Three-parameter models	Degree days/ temperature	$E = C + B_1(DD_{BT})$ $E = C + B_1(B_2 - T)^+$ $E = C + B_1(T - B_2)^+$	Seasonal weather-sensitive use (fuel in winter, electricity in summer for cooling); seasonal weather-sensitive demand.
Four-parameter, change-point model	Temperature	$E = C + B_1(B_3 - T)^+ - B_2(T - B_3)^+$ $E = C - B_1(B_3 - T)^+ - B_2(T - B_3)^+$	Seasonal weather-sensitive-use buildings with two cooling or two heating modes (i.e., two weather-sensitive slopes with one change point).
Five-parameter models	Degree days/ temperature	$E = C - B_1(DD_{TH}) + B_2(DD_{TC})$ $E = C + B_1(B_3 - T)^+ + B_2(T - B_4)^+$	Heating and cooling supplied by same meter. Change point $B_3 < B_4$; otherwise use four-parameter model.
Multivariate models	Degree days/ temperature, other independent variables	Combination form $E = c_0 + c_1x_1 + c_2x_2 + \ldots + c_nx_n$	Energy-use-dependent non-temperature-based variables (occupancy, production, etc.). Linear model form shown.

Figure 2: Steady-State, Single-Variate Models for Modeling Energy Use in Commercial Buildings

1.3 MEASUREMENT AND VERFICATION GUIDELINES – WHOLE-BUILDING

This section of the guidelines outlines the documentation that must be provided by the developer/designer/owner for the M&V stage, and describes the M&V process. This section of the guidelines is divided into three sub-sections: whole-building simulation; component isolation – new construction; and component isolation – retrofit.

Whole-Building Simulation + ECDMs In this section of the Guidelines the process of reviewing and approving projects that use whole-building simulation is outlined (Figure 3). In these projects the Applicant first develops a whole-building energy simulation file that represents the design features for the building that are code-compliant (i.e., base-case building); and then develops simulation input files that represent the proposed energy efficient project (i.e., proposed building). This base-case simulation includes building construction information, information about the heating, cooling, lighting and other equipment in the building, and schedules for the operation of the building's equipment, as well as a clear description of how the building meets the building Energy Code for the State of Ohio (i.e., ASHRAE Standard 90.1). Once this simulation input file has been developed it is submitted to OAQDA for review.

During this stage of the review process the OAQDA first determines that the energy efficient features of the base-case project represent the project and comply with the building energy code for the State of Ohio. Once this has been accomplished the Applicant then modifies the base-case simulation input file to represent the base-case + first Energy Conservation Design Measure (ECDM). This simulation file (i.e., base-case + ECDM #1) is then submitted to OAQDA for review.

Once OAQDA determines that this accurately represents the base-case + ECDM #1 condition then the applicant develops the next input file that represents the base-case simulation plus ECDM #2. In a similar fashion as the approval of the base case + ECDM#1 file the base case + ECDM #2 is reviewed by OAQDA to determine that it represents the base-case project plus only the second ECDM (i.e., base-case + ECDM #2).

This process is continued until all the ECDMs have been developed by the applicant and individually checked by OAQDA to determine that each file represents the base-case project plus each individual ECDM. Once all ECDMs have been checked a final proposed simulation project is developed that represents the base-case simulation input file plus all the ECDMs (i.e., the proposed whole-building simulation file). This proposed, whole-building simulation file then represents the proposed, energy efficient project that is being submitted for energy efficiency credits.

Whole Building Simulation + ECDMS

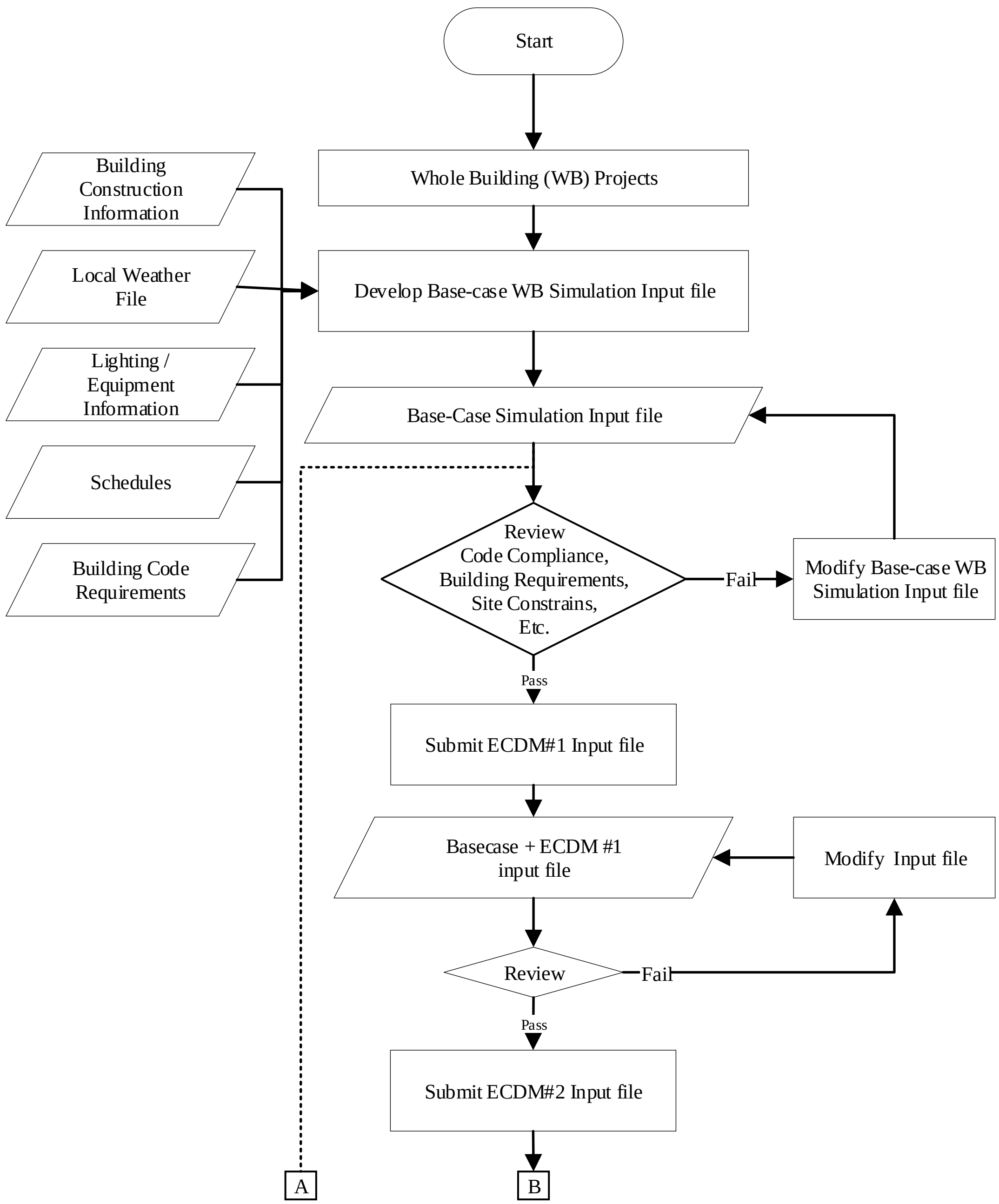


Figure 3: Whole-building Simulation using Multiple ECDMs.

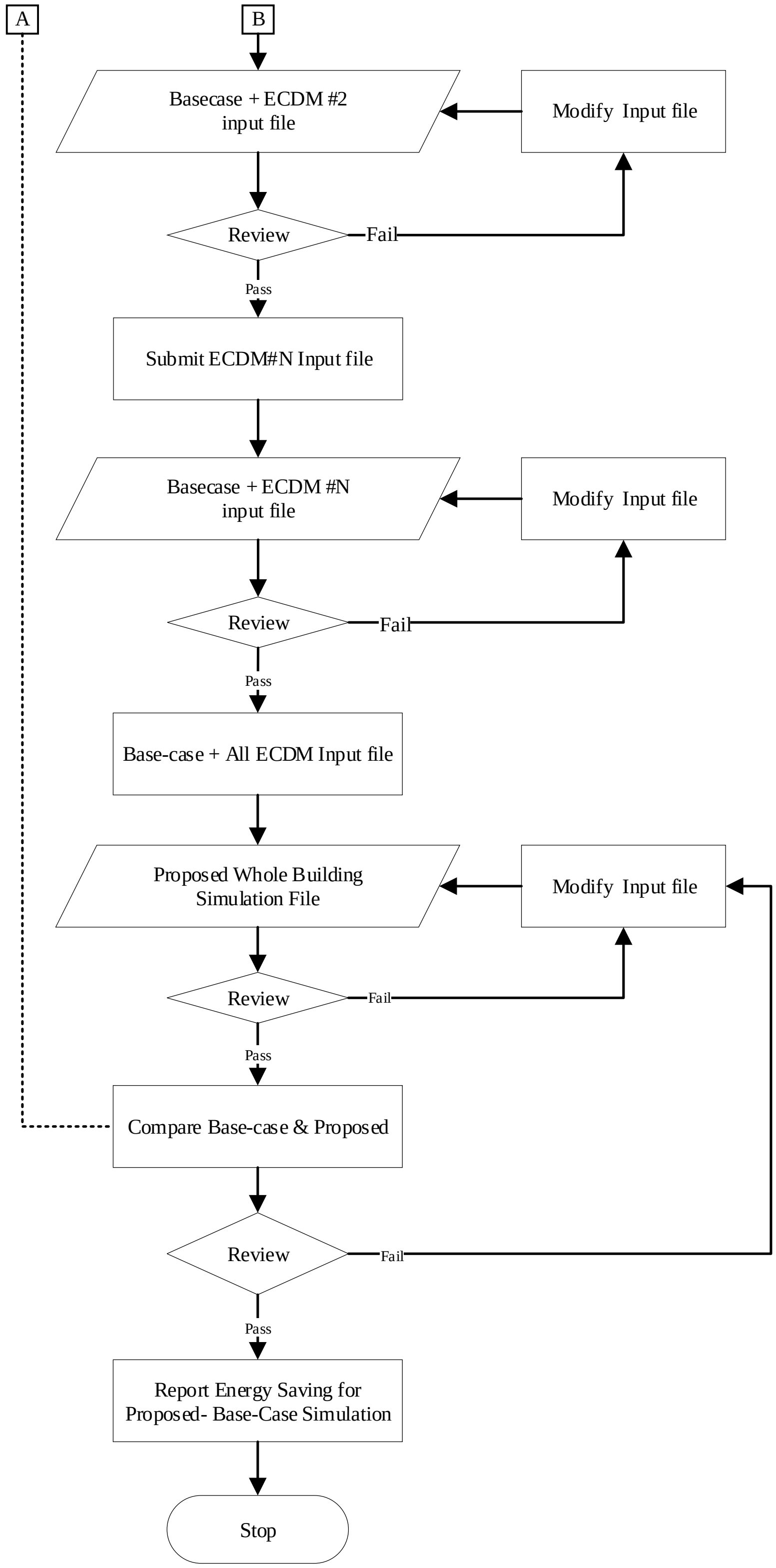


Figure 3: Whole-building Simulation using Multiple ECDMs (cont.)

1.4 MEASUREMENT AND VERFICATION GUIDELINES – COMPONENT ISOLATION, NEW CONSTRUCTION

Component Isolation In some projects it may be impracticable or unreasonable to develop a whole-building energy simulation to determine the energy efficiency potential for a project that is composed of one or more components. In such cases, an energy simulation model can be created for individual energy efficient components (i.e., component isolation, Doty & Turner, Energy Management Handbook, 2018). Such component isolation models can be classified as one of two types of component isolation models: component isolation – new construction; and component isolation – retrofit. Each method is described in the sections below.

Component Isolation – New Construction The review and analysis of a component isolation – new construction project is very similar to the review process for a whole-building simulation project with the exception that only the individual component that is being proposed is simulated by the Applicant (Figure 4). In such a project the Applicant develops two hourly simulation models of the individual component that is being proposed (i.e., a new chiller) and submits the component models for review. These two models represent the component as a base-case (or code-compliant model) and the new energy efficient component (i.e., above code). These component models are then reviewed by the OAQDA to determine if the meet requirements for the project. Once the OAQDA determines that the component model meets the requirements for the project, then the project can proceed.

In the upper portion of Figure 4 the review of the base-case and proposed component models can be seen. In this review the base-case model is inspected to determine that it represents the proposed component that has performance characteristics that meet code compliance (i.e., energy efficiency), as well as other characteristics required for the project (i.e., proper sizing, controls, etc.). Once the base-case model has been successfully reviewed, the second proposed model is reviewed in a similar fashion as the base-case model. This review includes a review of the performance parameters for the component to make sure they exceed code compliance.

The review must also determine that all other characteristics of the model are the same as the base-case model so that an accurate determination can be made of the changes to the energy efficiency (i.e., similar sizing of the models is the same, operating schedules, etc.).

Once the OAQDA reviews and approves both component models (i.e., base case and energy efficient model), then the Applicant submits a Metering Plan for review. In a similar fashion as a whole-building project, the Metering Plan is reviewed by the OAQDA to determine that is includes the proper metering to allow for the hourly measurement of the energy performance of the component(s) under all conditions.

After the approval of the Metering Plan by OAQDA, the Applicant then submits a Construction Plan for review. This Construction Plan is also reviewed by OAQDA to determine that the design intent of the project is carried through the construction process and results in an energy efficiency that meets the design intent. Once the Construction Plan is reviewed and approved by the OAQDA then the construction of the project can proceed.

When the construction has been completed the Applicant submits a Commissioning Report for review. In a similar fashion as a whole-building project, this Commissioning Report is reviewed by the OAQDA to determine that a proper on-site evaluation has been performed to determine that the energy performance of the new component(s) meets the design intent under all operating conditions.

After the Commissioning Report has been approved by the OAQDA, an occupancy permit can be issued and the collection of the metering data begins. This metering is performed by the Applicant in a similar fashion to metering of a whole-building project. The metering data from a component isolation includes (at a minimum) the energy use of the component and all necessary influencing parameters (i.e., weather data, equipment on/off schedule, indoor environmental conditions, etc.).

The collection of the metering data continues until a sufficient amount of data has been collected that is representative of all operating conditions for the component. This metering period varies depending upon the type of building component that has been installed: weather dependent or weather-independent. In cases where weather-dependent equipment has been installed (i.e., cooling or heating equipment), the period of time needed for proper metering should cover all expected weather conditions for a site. For example, if the system component is a cooling system, then the metering period should cover a sufficient period of the cooling season such that a regression model can be applied to the data (using the algorithms contained in the ASHRAE Inverse Model Toolkit (Figure 4). The coefficients determined by the IMT are then compared to similar coefficients developed from the energy use of a simulated component model operating under similar conditions (i.e., same schedules, setpoints, etc.). If there are significant differences in the operating schedules of the facility, then sufficient metered data need to be collected for all anticipated operating schedules (i.e., weekday and weekend). Once sufficient data have been collected, the energy savings can be calculated by comparing the IMT coefficients from the measured data to the similar coefficients from the simulated component model using the IMT with similar conditions (i.e., weather data, schedules, etc.)

For weather-independent components (i.e., new energy-efficient exterior lighting), it is also possible that a shorter duration metering period can be used to gather sufficient data for the determination of the IMT coefficients. For example, in a project where exterior lighting was controlled by a seasonal time clock is replaced with energy efficient exterior lighting that is controlled by photo sensors short-term measurements may be sufficient to determine the energy savings from the new energy efficient lighting. Such short-term electric power measurements (i.e., kW) can then be used to determine the energy use of the new, energy efficient lighting that can then be multiplied by the hours of operation that are representative of the seasonal time clock (i.e., pre-retrofit) versus the hours of operation using the new photocell controls (i.e., post-retrofit) and the savings calculated.

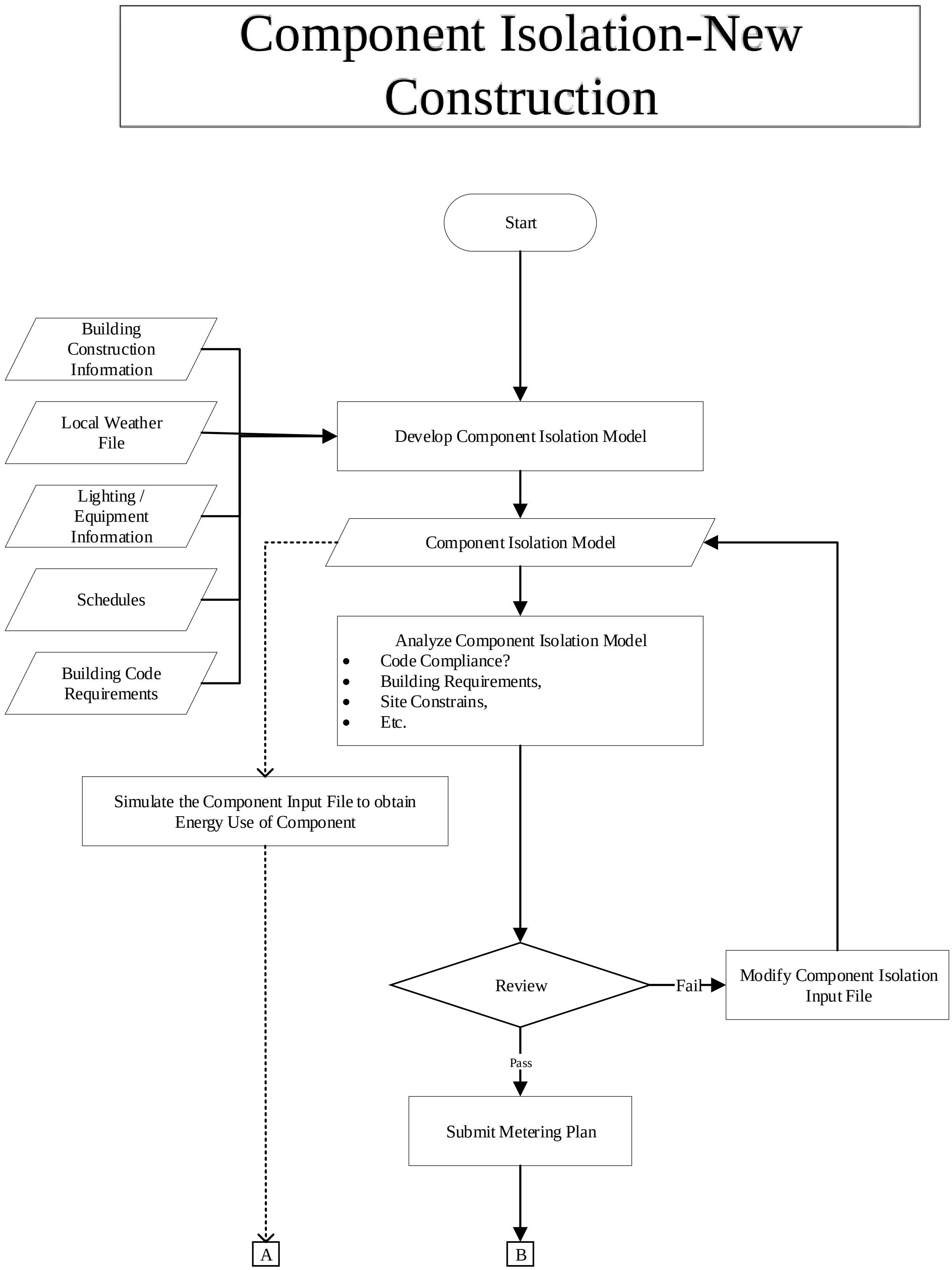


Figure 4: Component Isolation – New Construction

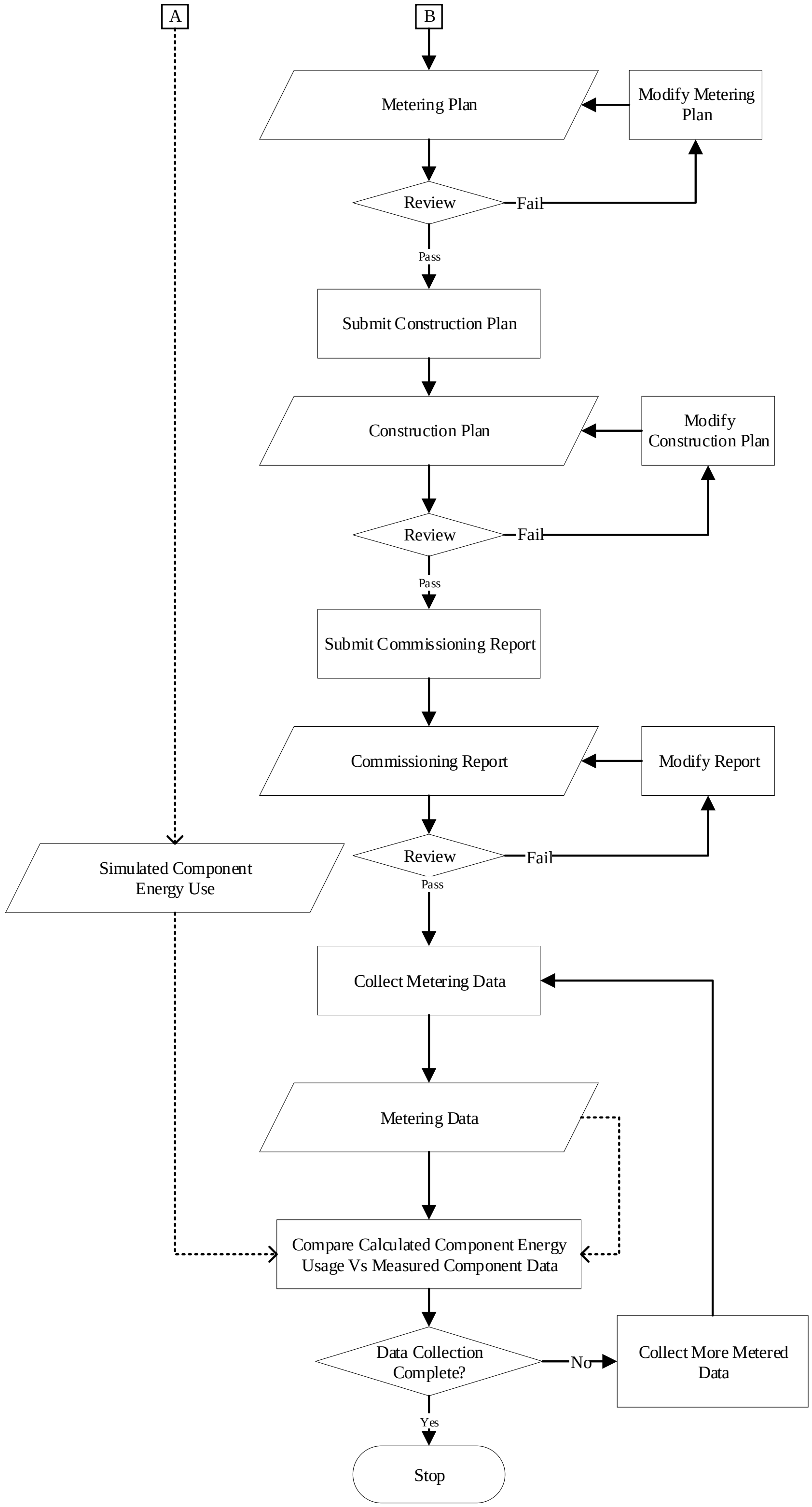


Figure 4: Component Isolation – New Construction (cont.)

1.5 MEASUREMENT AND VERFICATION GUIDELINES – COMPONENT ISOLATION, RETROFIT

Component Isolation – Retrofit The process for calculating energy savings using a component isolation model in a project that contains pre-retrofit and post-retrofit data is shown in Figure 5. In such projects pre-retrofit and post-retrofit data are available for the component that is being retrofitted. Direct measurements of the energy savings can be determined by analyzing the pre and post-retrofit data. In this type of project the Applicant submits a component isolation model(s) for component(s) being retrofitted. These models (i.e., base-case and proposed energy efficient component) are reviewed by the OAQDA to determine that the base-case model meets code compliance and that the proposed, energy-efficient model is more efficient than the base-case model. In addition, both models are inspected to determine that they capture the necessary project characteristics (i.e., schedules, setpoints, etc.).

Once the model(s) have been approved by the OAQDA, the Applicant then submits a Metering Plan for review by the OAQDA. This metering plan is inspected to determine that it captures the energy use of the component(s) and all other operating parameters for a sufficient model (i.e., schedules, temperature setpoints, etc.). After the Metering Plan has been approved by the OAQDA, the collection of the pre-retrofit data can begin.

While the pre-retrofit data are being collected, the Applicant also submits a post-retrofit Metering Plan for review and approval by the OAQDA. Once this post-retrofit Metering Plan is approved, the Applicant submits a Construction Plan for review and approval. Construction on the project can then begin when the Construction Plan is approved by the OAQDA. When the construction is completed, the Applicant submits a Commissioning Plan for review and approval. When the Commissioning Plan is approved, the post-retrofit metering begins.

After sufficient data have been collected in the post-retrofit period, the pre-retrofit data and post-retrofit data can be analyzed using the ASHRAE IMT, or other appropriate model, and the savings calculated by comparing the pre-retrofit and post-retrofit data for a sufficient data collection period (i.e., weather dependent vs non-weather dependent).

In the case that the measured savings (i.e., pre-retrofit vs post-retrofit) meet the estimated energy savings then the savings verification can be considered complete. When savings do not meet the anticipated savings, then the pre-retrofit and post-retrofit models can be inspected to determine the reason for the difference in savings. If it is determined that a significant change has occurred to the project, then an adjustment may be needed for the savings determination. Such an adjustment would need to be reviewed and approved by the OAQDA. Examples of such adjustments might include projects where the intended usage of the equipment is changed due to circumstances beyond the control of the applicant.

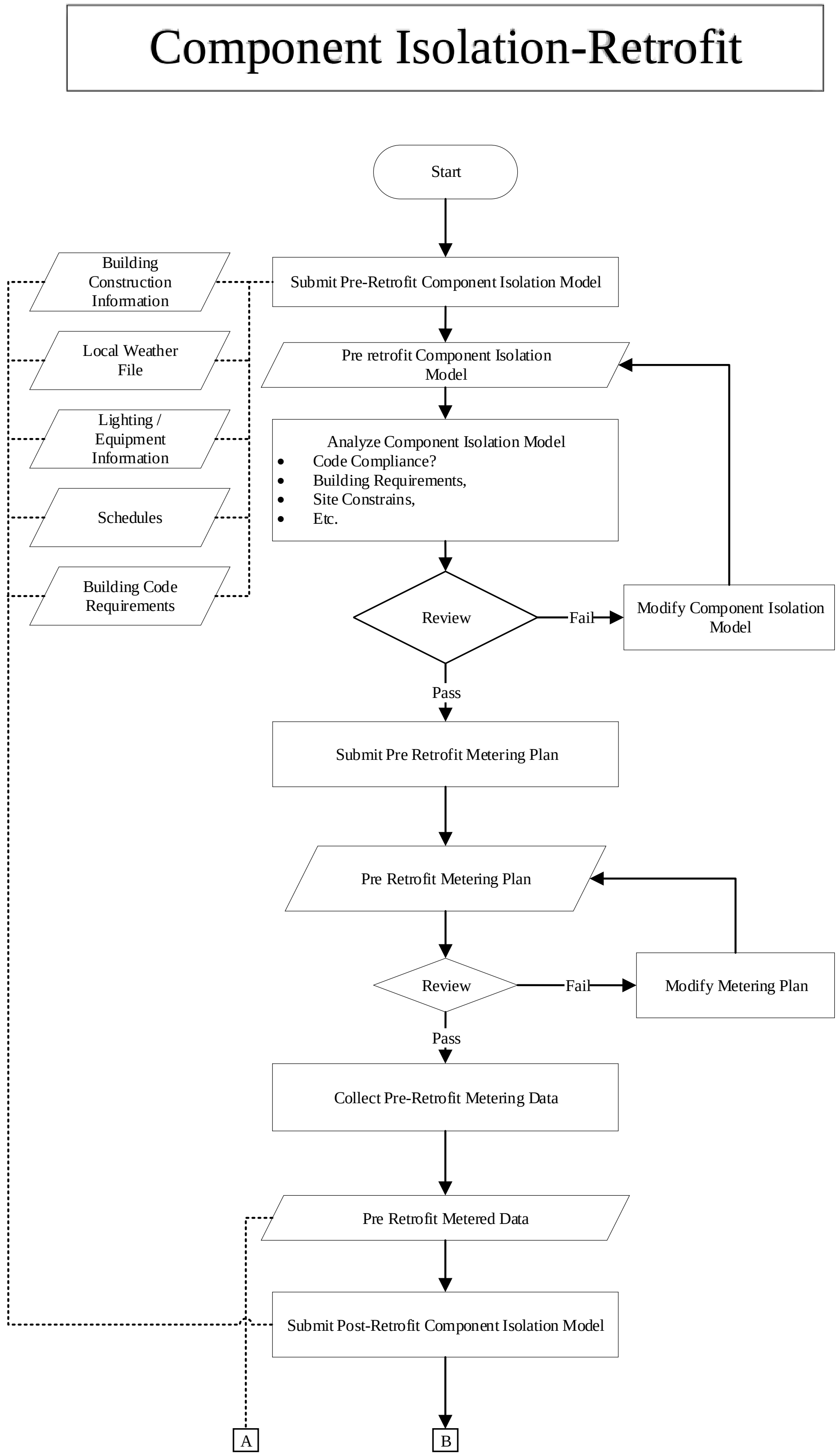


Figure 5: Component Isolation – Retrofit

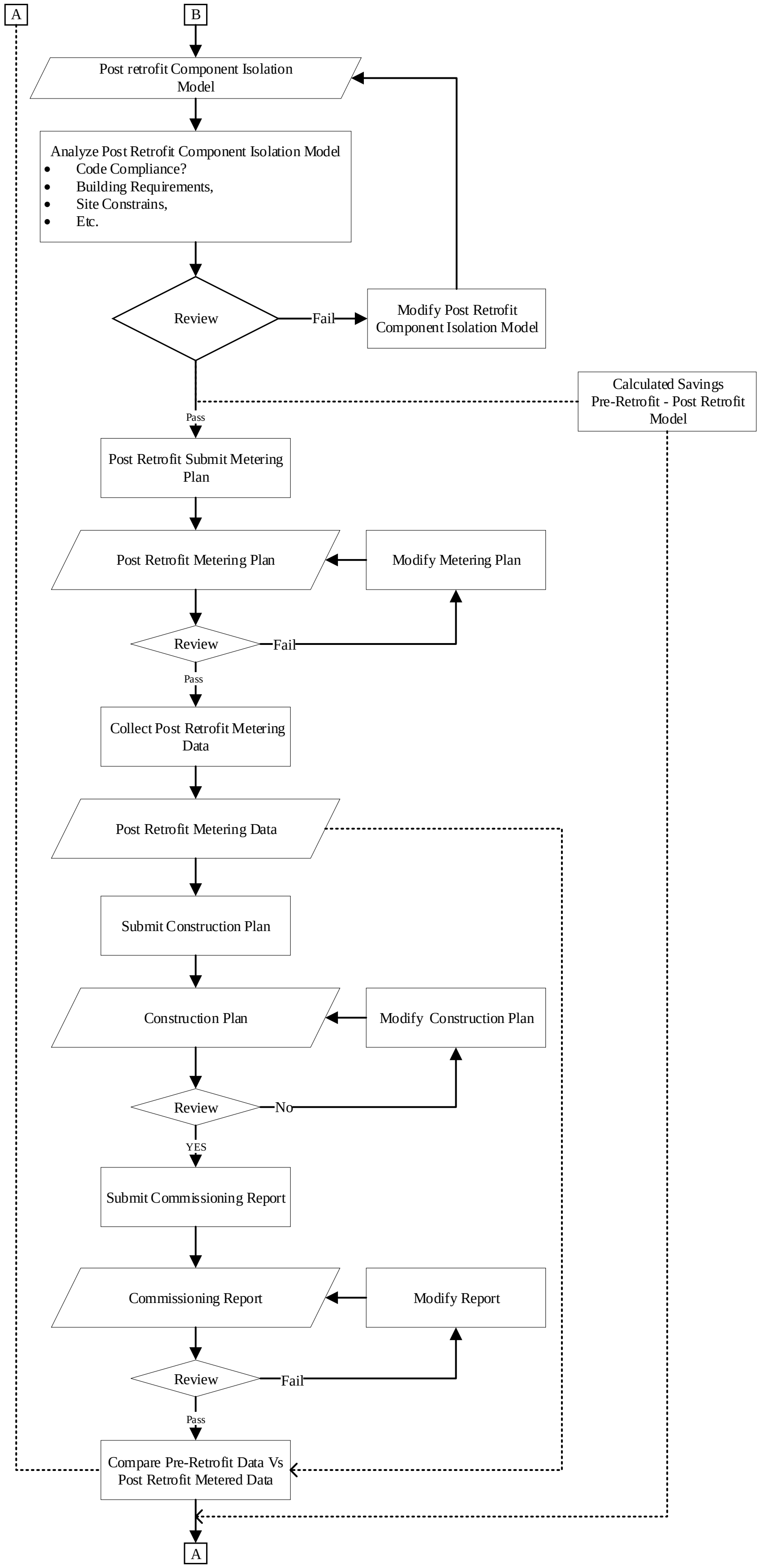

A
B
Post retrofit Component Isolation Model
Analyze Post Retrofit Component Isolation Model
Code Compliance?
Building Requirements,
Site Constrains,
Etc.
Review
Fail
Modify Post Retrofit Component Isolation Model
Calculated Savings Pre-Retrofit - Post Retrofit Model
Pass
Post Retrofit Submit Metering Plan
Post Retrofit Metering Plan
Modify Metering Plan
Review
Fail
Pass
Collect Post Retrofit Metering Data
Post Retrofit Metering Data
Submit Construction Plan
Construction Plan
Modify Construction Plan
Review
No
YES
Submit Commissioning Report
Commissioning Report
Modify Report
Review
Fail
Pass
Compare Pre-Retrofit Data Vs Post Retrofit Metered Data
A

Figure 5: Component Isolation – Retrofit (cont.)

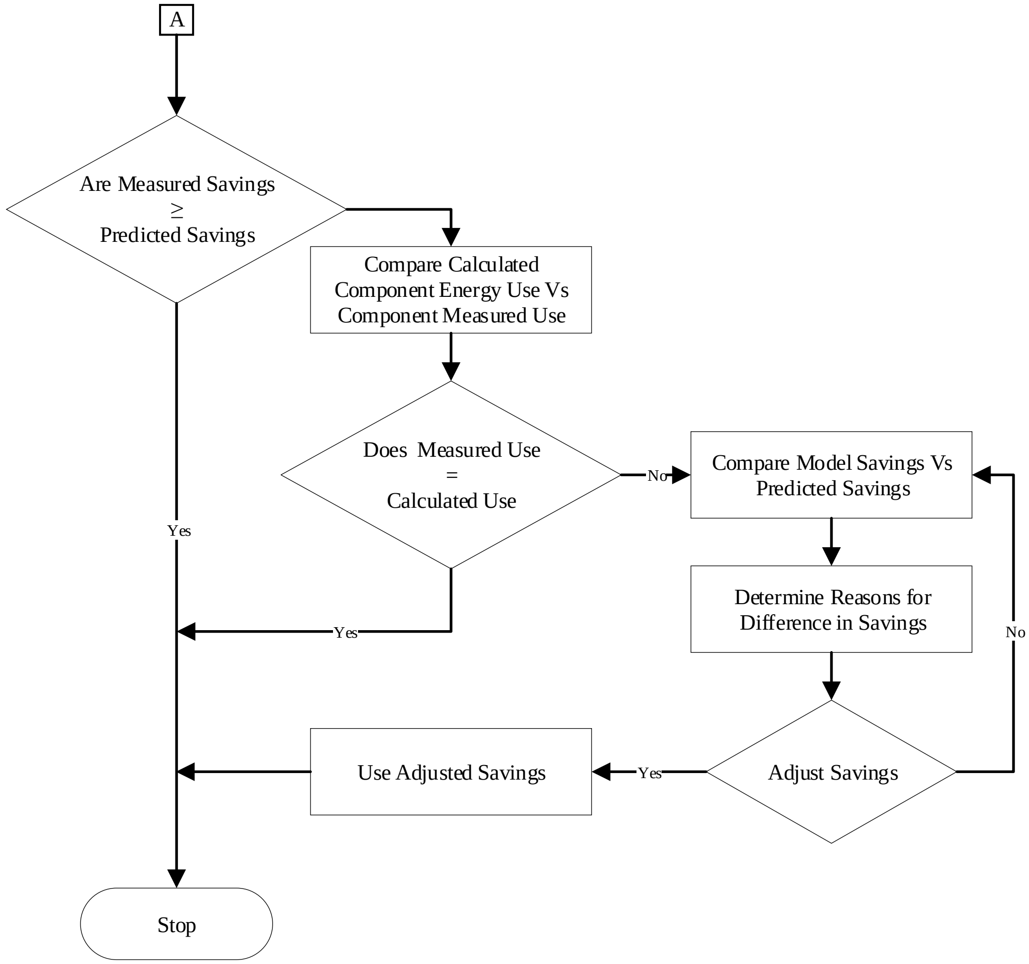


Figure 5: Component Isolation – Retrofit (cont.)

1.6 MEASUREMENT AND VERFICATION GUIDELINES – COMPONENT ISOLATION, RENEWABLE PROJECT

The process for calculating the energy production using a component isolation model in a project that contains a renewable energy project is shown in Figure 6. In such projects a component isolation model is developed to estimate the renewable energy the system will produce given average weather conditions for the location where it is installed. Direct measurements of the energy produced by the system are then measured once the system is installed and compared against the estimates from the component model.

Once the model(s) have been approved by the OAQDA, the Applicant then submits a Metering Plan for review by the OAQDA. This metering plan is inspected to determine that it captures the energy production of the system, and should include information about all other operating parameters for a sufficient model (i.e., system configuration, system type, intended manufacturer, anticipated degradation etc.). After the Metering Plan has been approved by the OAQDA, the Applicant submits a Construction Plan for review and approval. Construction on the project can then begin when the Construction Plan is approved by the OAQDA. When the construction is completed, the Applicant submits a Commissioning Plan for review and approval. When the Commissioning Plan is approved, the project metering begins.

After sufficient data have been collected the measured performance is compared to the estimated systems performance, including any adjustments for significant changes in the actual weather data vs the average year weather data.

In the case that the measured production does not equal or exceed the estimated energy production, then the component model can be inspected to determine the reason for the difference in savings, and site-visit(s) scheduled as needed to determine why the renewable system performance does not match the estimated performance.

If it is determined that a significant change has occurred to the project, then an adjustment may be needed for the energy production. Such an adjustment would need to be reviewed and approved by the OAQDA. Examples of such adjustments might include projects where shading from a nearby building was greater than anticipated, or the manufacturer’s equipment is not performing as expected, which will require an adjustment to the annual energy production from the system because of circumstances beyond the control of the applicant.

Once the adjustment is made and the system is performing satisfactorily, the data collection can resume so OAQDA can credit the applicant with the appropriate amount of renewable energy generation.

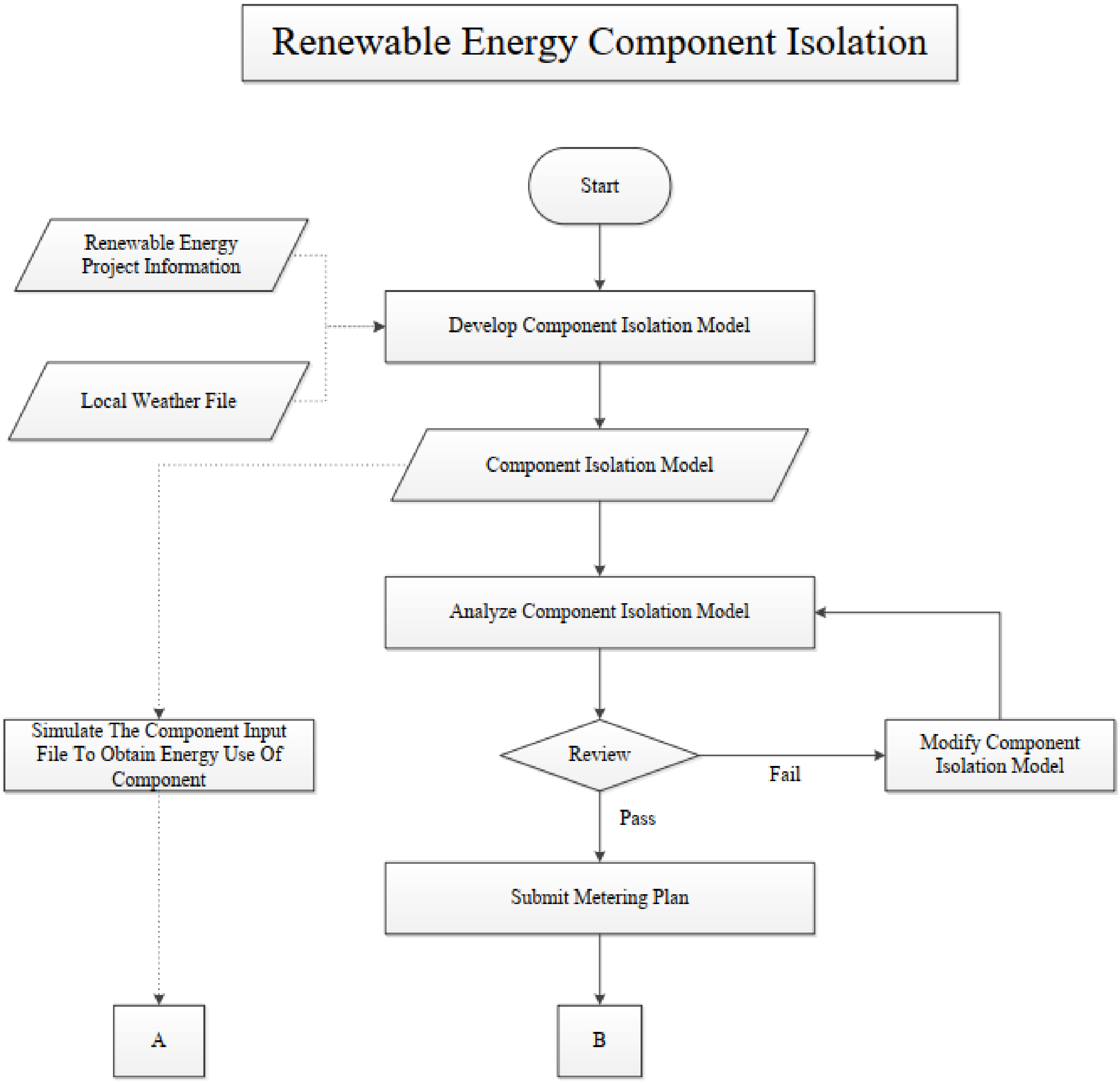


Figure 6: Component Isolation - Renewable Energy Project

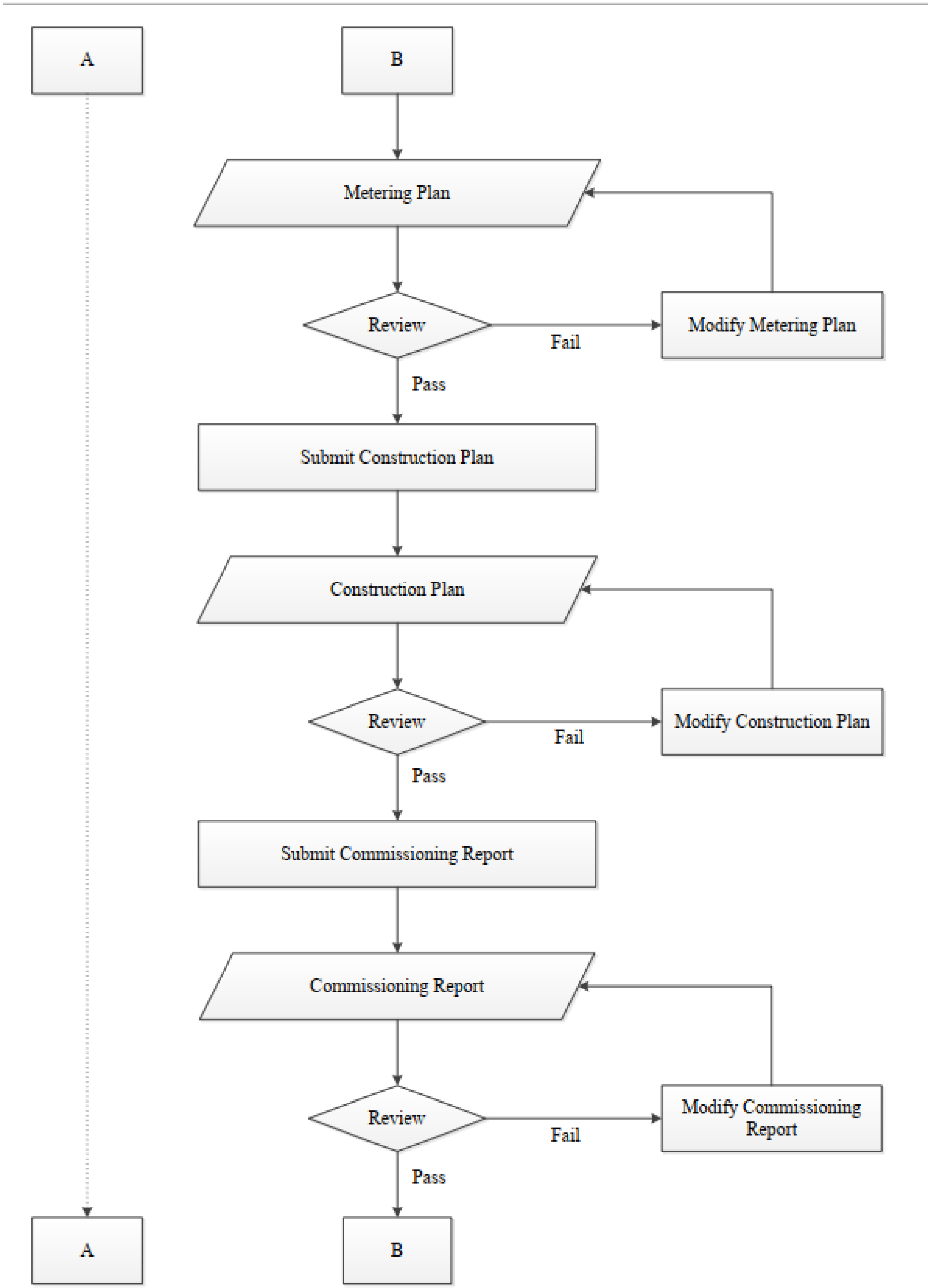


Figure 6: Component Isolation - Renewable Energy Project (cont).

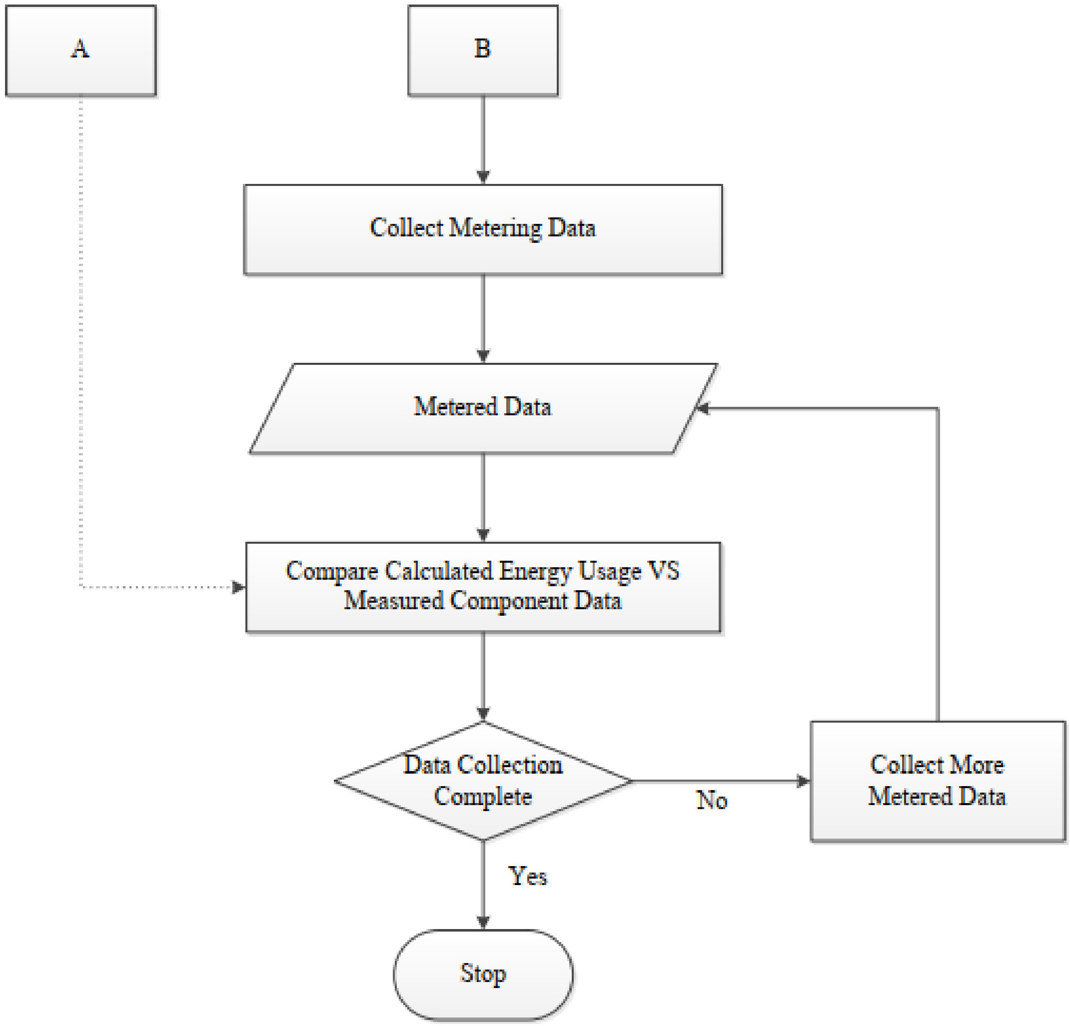


Figure 6: Component Isolation - Renewable Energy Project (cont).

1.7 MEASUREM7NT AND VERFICATION GUIDELINES – COMPONENT ISOLATION, CRITERIA POLLUTANT (NEW PROJECT)

The process for calculating pollution reduction using a component isolation model for a new project that reduces a criteria pollutant(s) is shown in Figure 7. In such projects the component being installed is evaluated by OAQDA to determine that it is producing criteria pollutant(s) below the rate that is required by the Ohio Environmental Protection Agency (OEPA). In such cases where the new component is not in compliance with OEPA requirements, the applicant will be notified and the application sent back to the applicant for revision.

In the case where the claimed criteria pollutant(s) are below the rate established by the OEPA, then the OAQDA will notify the applicant to:

1. Proceed with the submittal of a Measurement and Verification (M&V) plan for the equipment. This proposed M&V plan will then be reviewed by the OAQDA to determine that the procedures for measuring the on-site criteria pollutant(s) comply with the OEPA criteria pollutant(s) measurement procedures.
2. Once the M&V plan is approved, the project can proceed with the submittal of the Commissioning Plan. This Commissioning Plan will describe the procedures the applicant will use to apply the proposed M&V procedures to the equipment once the equipment is installed on-site.
3. The OAQDA then reviews the Commissioning Plan to determine that the proposed plan complies with the OEPA measurement procedures.
4. Once the Commissioning Plan is approved the applicant can then install the equipment, proceed with the on-site measurements of the criteria pollutant(s) and submit the preliminary M&V report to the OAQDA for approval.
5. The OAQDA then reviews the preliminary report to determine that the criteria pollutant(s) rate is at or below the rates acceptable to the OEPA.
6. If the rates are above the allowable rate established by the OEPA, then the applicant will be notified to determine the cause of the difference, correct the problem and resubmit.
7. If the criteria pollutant(s) are determined to be below the rates required by the OEPA then the building/facility can be issued an operating permit and the continuous measurement period of the pollutant(s) begins.
8. This procedures continues throughout the life of the equipment until the building/facility is demolished and the equipment retired.

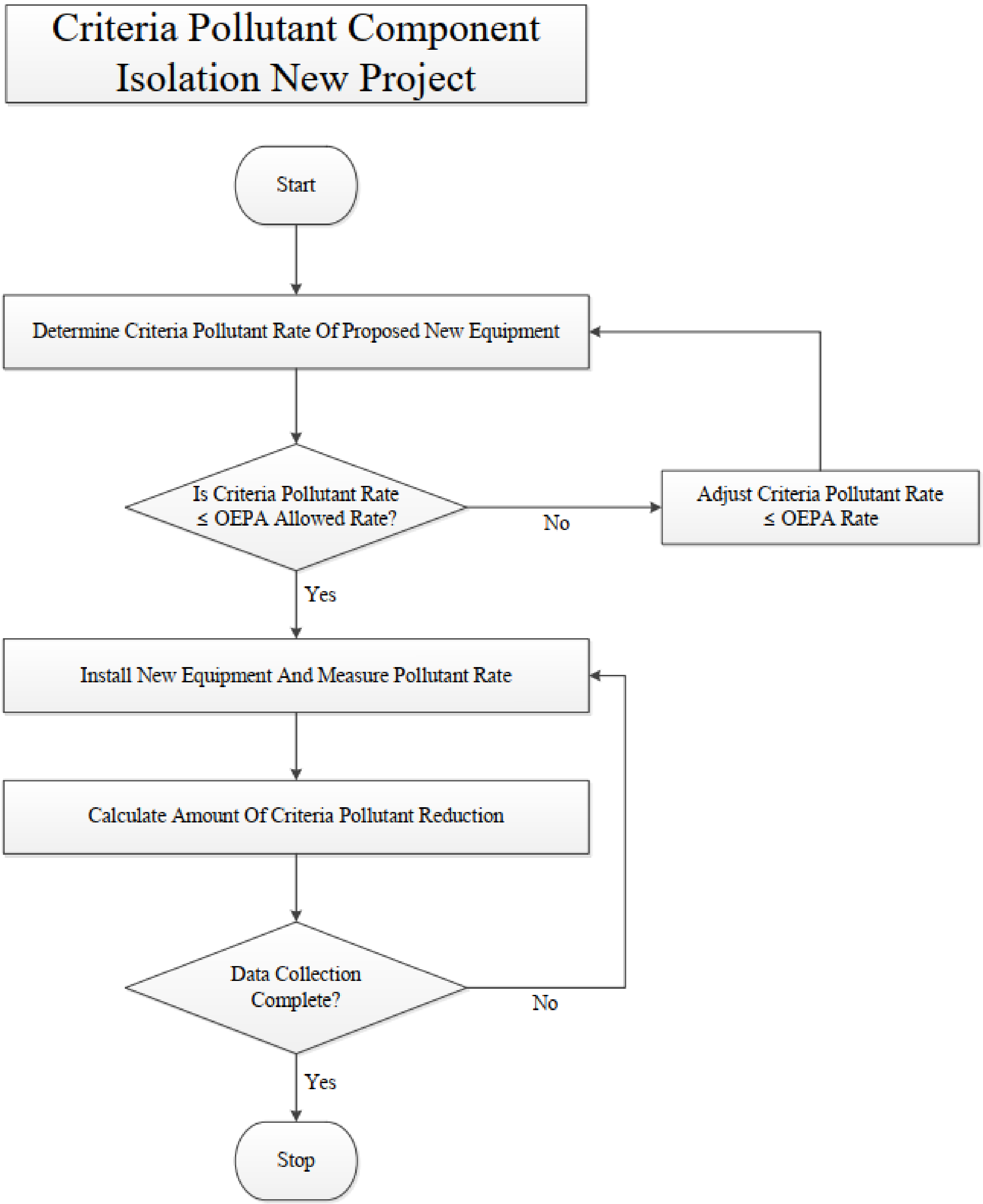


Figure 7: Component Isolation – Criteria Pollutant, New Project

1.8 MEASUREMENT AND VERFICATION GUIDELINES – COMPONENT ISOLATION, CRITERIA POLLUTANT (RETROFIT PROJECT)

The process for calculating pollution reduction using a component isolation model for a retrofit project that reduces a criteria pollutant(s) is shown in Figure 8. In such projects the new component being installed is first evaluated by OAQDA to determine that it is producing criteria pollutant(s) below the rate that is required by the Ohio Environmental Protection Agency (OEPA). In such cases where the new component is not in compliance with OEPA requirements, the applicant will be notified and the application sent back to the applicant for revision.

In the case where the claimed criteria pollutant(s) of the new equipment are below the rate established by the OEPA, then the OAQDA will notify the applicant to:

1. Proceed with the submittal of a Measurement and Verification (M&V) plan for the existing equipment and new equipment. This proposed M&V plan will then be reviewed by the OAQDA to determine that the procedures for measuring the on-site criteria pollutant(s) comply with the OEPA criteria pollutant(s) measurement procedures.
2. Once the M&V plan is approved, the project can proceed with the measurement of the criteria pollutant(s) of the existing equipment and the Commissioning Plan for the installing and testing the new equipment. The criteria pollutant rate of the existing equipment will be measured by the applicant using the procedures determined in the approved M&V plan. These measurements must cover all operating conditions for the equipment, especially for equipment that has multiple firing rates for the burners contained in the equipment. The Commissioning Plan will describe the procedures the applicant will use to apply the proposed M&V procedures to the new equipment once the new equipment is installed on-site.
3. The OAQDA then reviews measurements of the existing equipment to determine that they have been performed in compliance with OEPA procedures and reviews the Commissioning Plan for the new equipment to determine that the proposed plan complies with the OEPA measurement procedures.
4. Once the Measurement of the existing equipment and the Commissioning Plan is approved the applicant can then remove the existing equipment, install the new equipment, proceed with the on-site measurements of the criteria pollutant(s) on the new equipment and submit the preliminary M&V report to the OAQDA for approval.
5. The OAQDA then reviews the preliminary report to determine that the criteria pollutant(s) rate for the new equipment is at or below the rates acceptable to the OEPA.
6. If the rates are above the allowable rate established by the OEPA, then the applicant will be notified to determine the cause of the difference, correct the problem and resubmit.
7. If the criteria pollutant(s) are determined to be below the rates required by the OEPA then the building/facility can be issued an operating permit and the continuous measurement period of the pollutant(s) begins.

8. This procedures continues throughout the life of the equipment until the building/facility is demolished and the equipment retired.

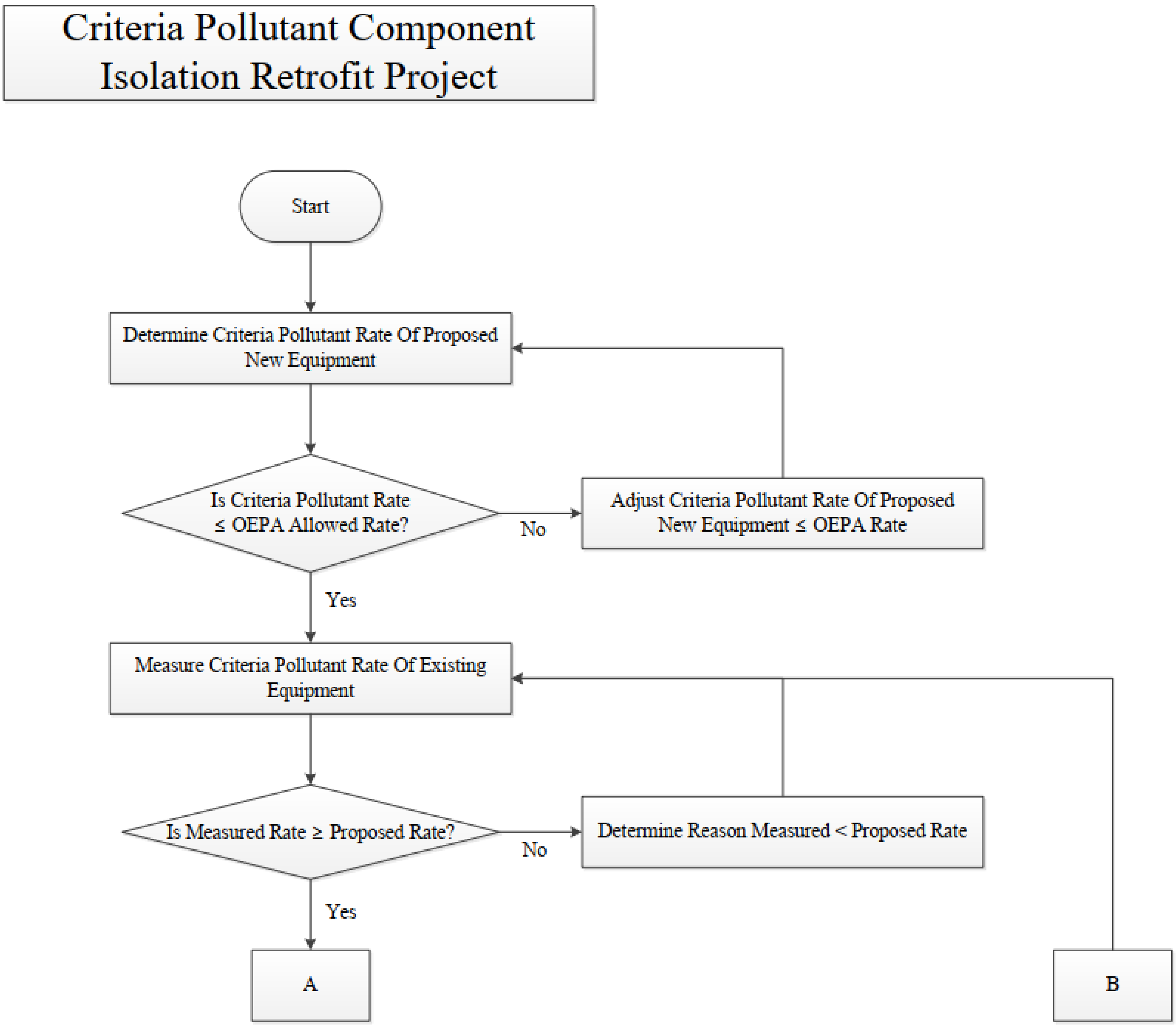


Figure 8: Component Isolation – Criteria Pollutant, Retrofit Project

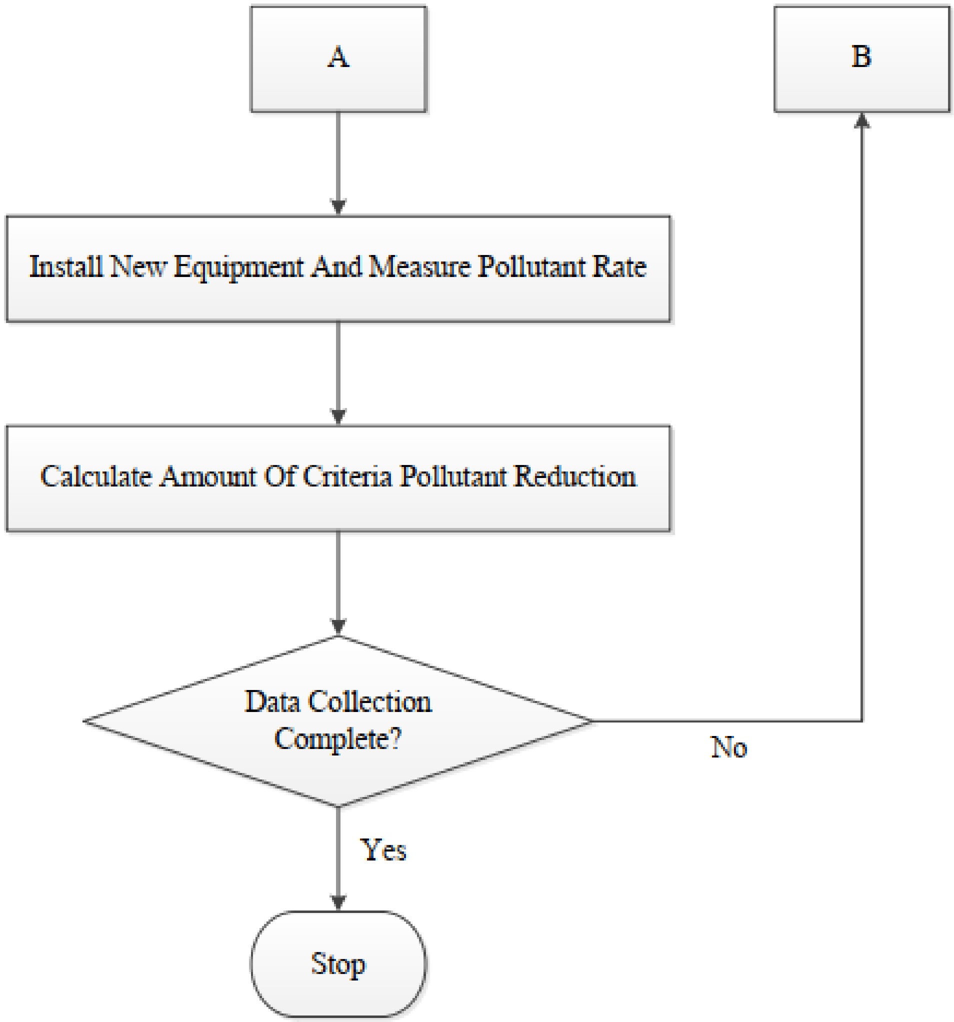


Figure 8: Component Isolation – Criteria Pollutant, Retrofit Project (cont).

1.9 BEFORE-AFTER UTILITY BILLING ANALYSIS (12 MONTH OPERATION)

The Before-After Utility Billing Analysis for buildings/facilities that are operated 12 months out of the year is shown in Figure 9. In this analysis 12 months of utility bills are collected for each energy meter in the facility before and after the retrofit (i.e., natural gas, electricity), and a separate analysis is performed on each utility. The corresponding daily average dry bulb temperature from a nearby NOAA station that is coincident with the utility billing data is also collected.

The first step in the analysis is to divide the energy consumed for each monthly billing period by the days in the billing period, which results in daily average energy use for the billing period. Next, the daily average dry bulb temperature from the nearby NOAA station is divided into periods that align with the utility billing periods and the average daily temperature for the billing period is calculated and paired with the average daily utility billing period energy use.

In the next step, using the pre-retrofit data, all ASHRAE IMT models are calculated for each utility for the pre-retrofit period (i.e., 1P, 2P, 3PC, 3PH, 4P and 5P), and the best-fitting model, that is appropriate, is chosen that has the lowest CV(RMSE) and NMBE. The “appropriateness” of the models can be determined using the tests developed by Paulus and Claridge (2015), which are shown in Figures 10 through 12. This process is then repeated for the post-retrofit period.

The annual energy savings is then calculated using the pre-retrofit and post-retrofit IMT models and the post-retrofit daily dry bulb temperature. Next, the annual energy savings, calculated with the pre-retrofit and post-retrofit IMT models is then compared to the estimated savings, and if the savings are less than the estimated savings the reason for the difference needs to be determined and reported to the OAQDA so that an appropriate remedy can be applied. Otherwise, the data collection continues until the project is complete.

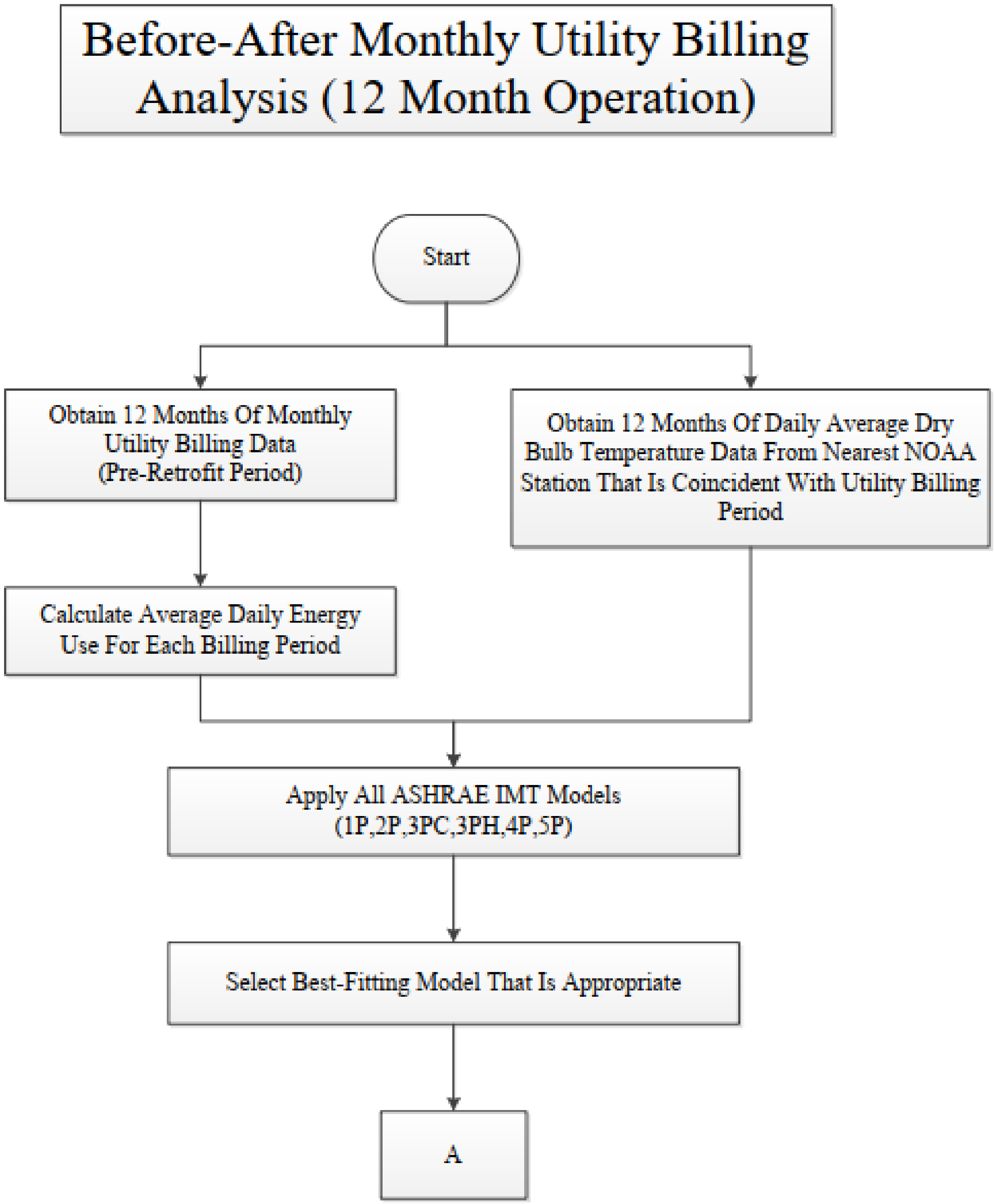


Figure 9: Before-After Monthly Utility Billing Analysis (12 Month Operation).

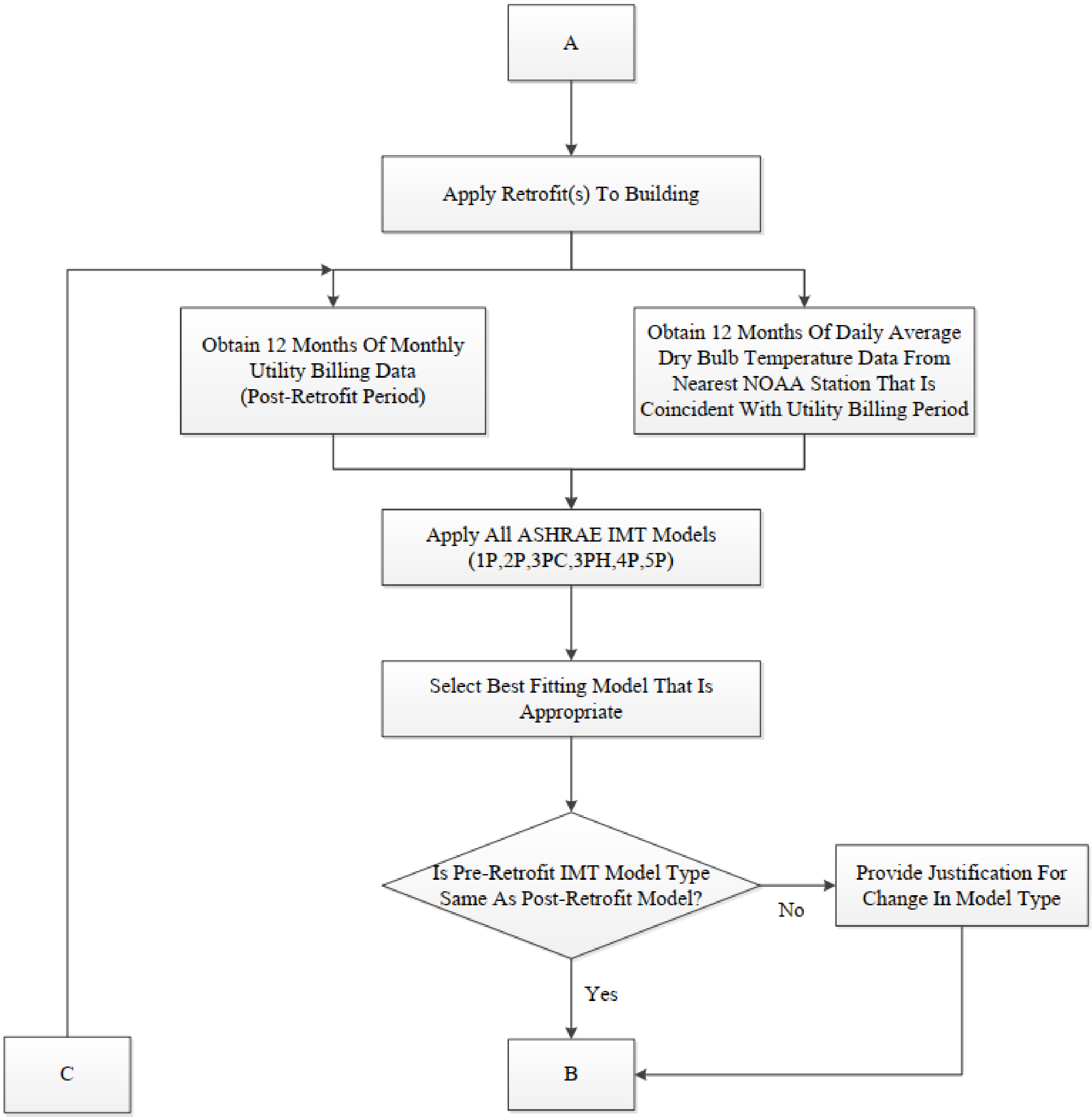


Figure 9: Before-After Monthly Utility Billing Analysis (12 Month Operation) (cont)..

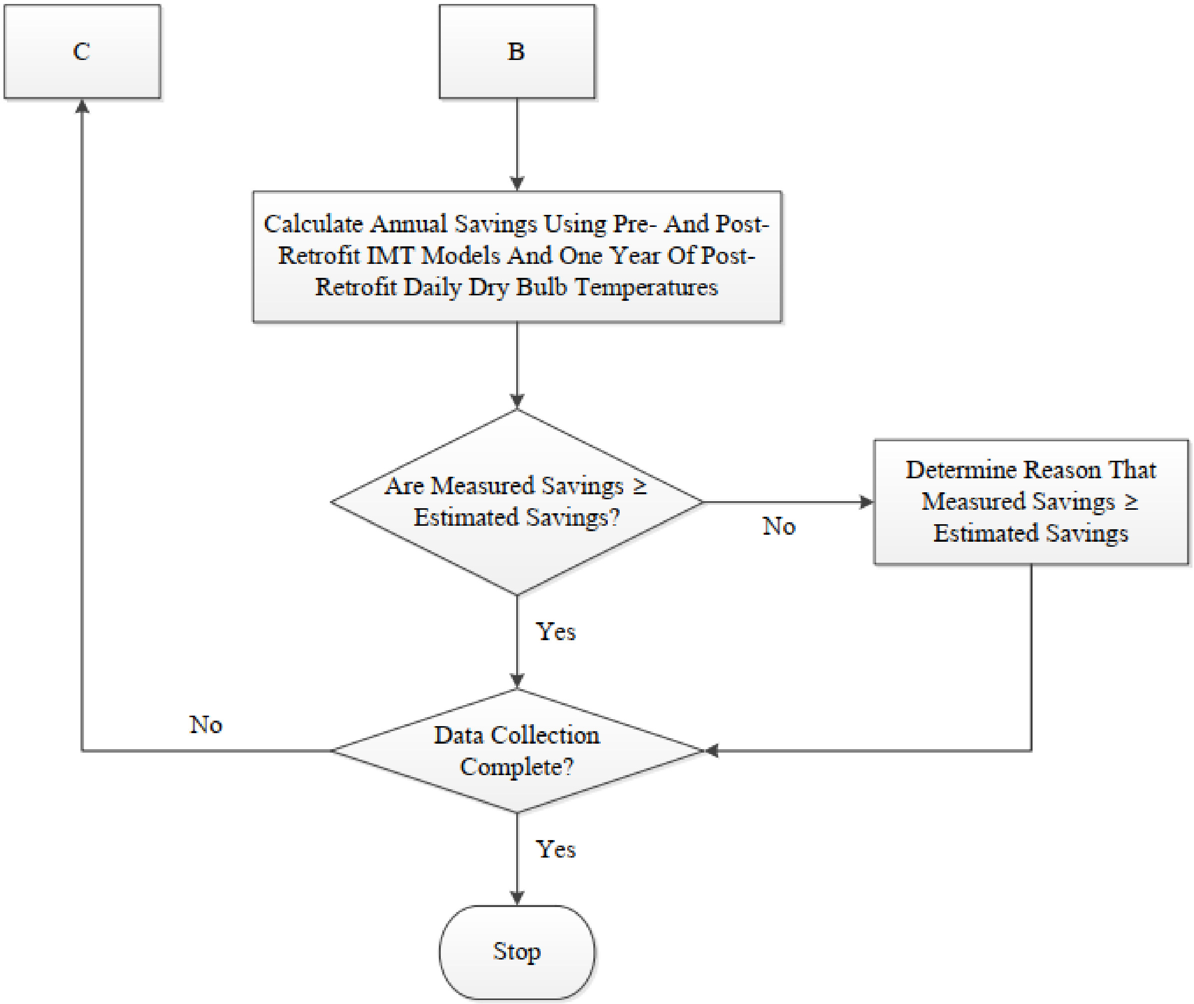


Figure 9: Before-After Monthly Utility Billing Analysis (12 Month Operation) (cont)..

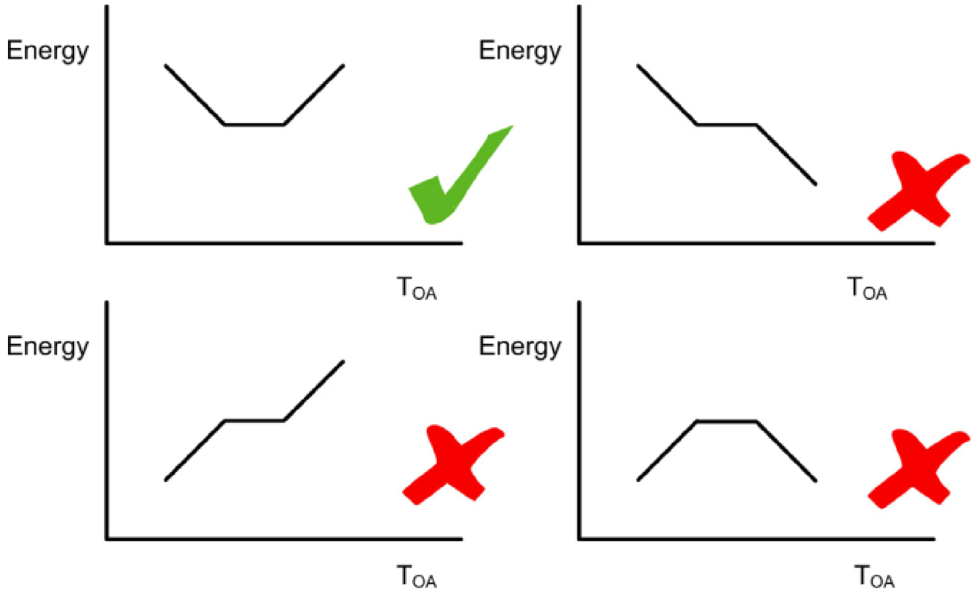


Figure 10: Permitted and Non-permitted Shapes for 5P models (Paulus et al. 2015)

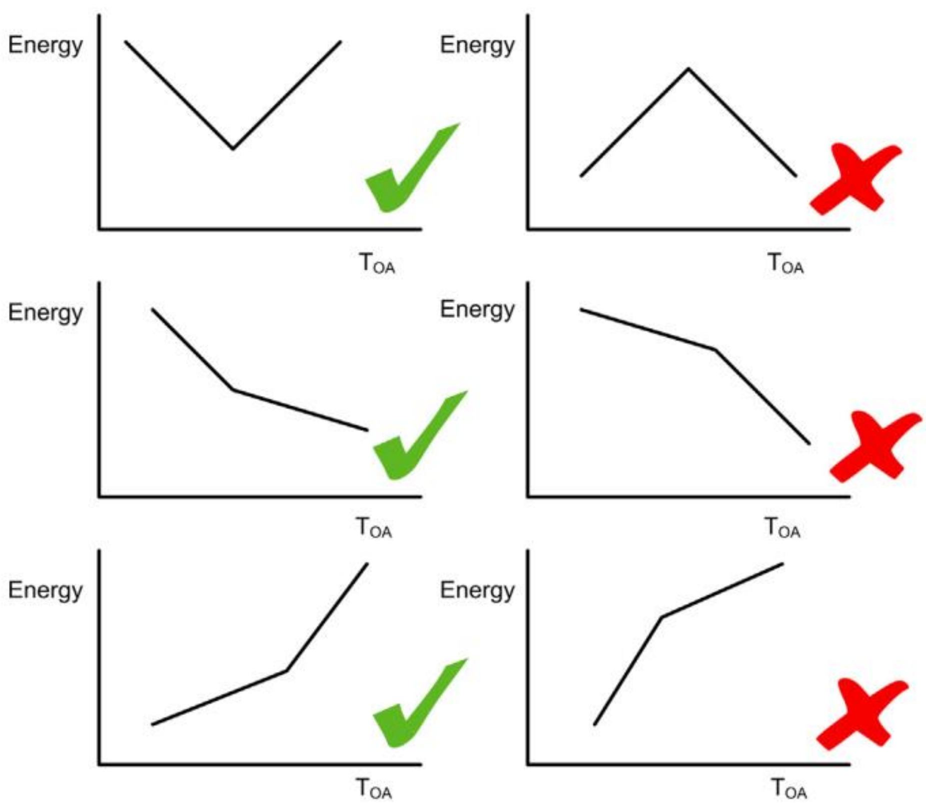


Figure 11: Permitted and Non-permitted Shapes for the 4P Models.

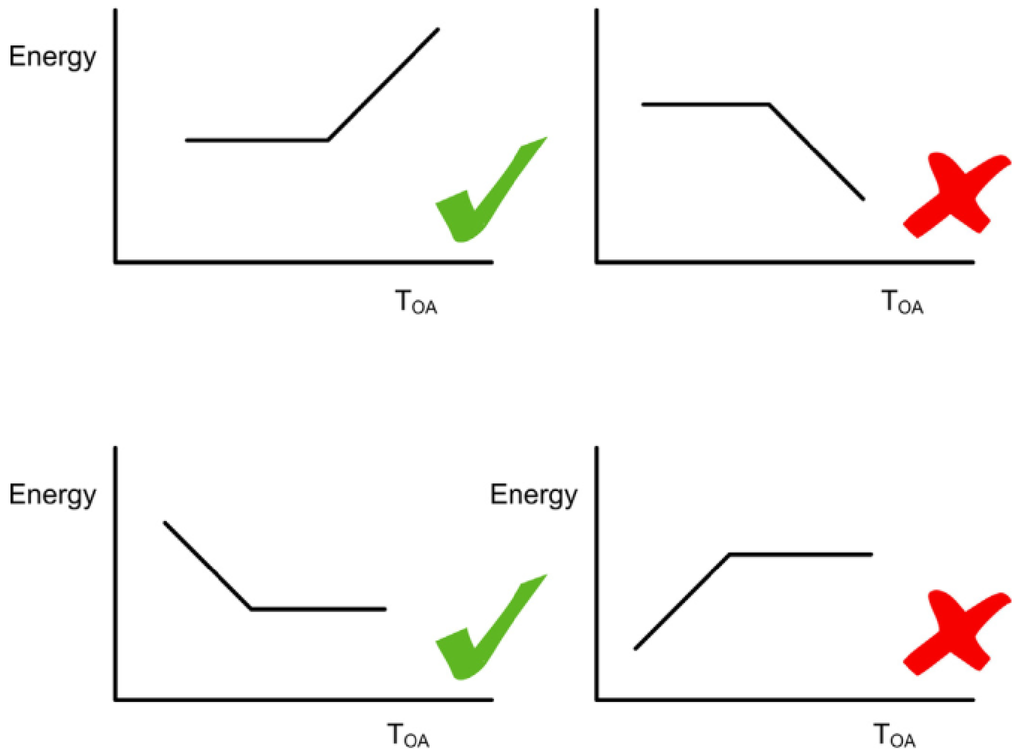


Figure 12: Permitted and Non-permitted Shapes for the 3PC Models (upper) and 3PH Models (lower).

1.10 BEFORE-AFTER UTILITY BILLING ANALYSIS (K-12 SCHOOLS & UNIVERSITIES)

The Before-After Utility Billing Analysis for buildings/facilities that are operated 9 months out of the year (i.e., school year/summertime) is shown in Figure 13. In this analysis 12 months of utility bills are collected for each energy meter in the facility before and after the retrofit (i.e., natural gas, electricity), and a separate analysis is performed on each utility. The corresponding daily average dry bulb temperature from a nearby NOAA station that is coincident with the utility billing data is also collected.

In a similar fashion as buildings with a 12-month operation, the first step in the analysis is to divide the energy consumed for each monthly billing period by the days in the billing period, which results in daily average energy use for the billing period. Next, the daily average dry bulb temperature from the nearby NOAA station is divided into periods that align with the utility billing periods and the average daily temperature for the billing period is calculated and paired with the average daily utility billing period energy use.

However, for buildings with a 9 month operation (i.e., school year/summertime) the pre-retrofit and post-retrofit utility bills are first separated into utility bills during the school year and utility bills during the summertime period. For utility bills during the school year all, in the next step, using the pre-retrofit data, all ASHRAE IMT models are calculated for each utility for the pre-retrofit period (i.e., 1P, 2P, 3PC, 3PH, 4P and 5P), and the best-fitting model, that is appropriate, is chosen that has the lowest CV(RMSE) and NMBE. The “appropriateness” of the models can be determined using the tests developed by Paulus and Claridge (2015), which are shown in Figures 10 through 12. This process is then repeated for the post-retrofit period.

For the utility bills during the summertime period the ASHRAE 1P or 2P models are applied to the data to determine the best-fitting model that is appropriate, using the lowest CV(RMSE) and NMBE. The “appropriateness” of the models is also determined using the tests developed by Paulus and Claridge (2015),

The annual energy savings is then calculated using the school year and summertime, pre-retrofit and post-retrofit IMT models and the post-retrofit daily dry bulb temperature. Then, the annual energy savings, calculated with the pre-retrofit and post-retrofit IMT models is then compared to the estimated savings, and if the savings are less than the estimated savings the reason for the difference needs to be determined and reported to the OAQDA so that an appropriate remedy can be applied. Otherwise, the data collection continues until the project is complete.

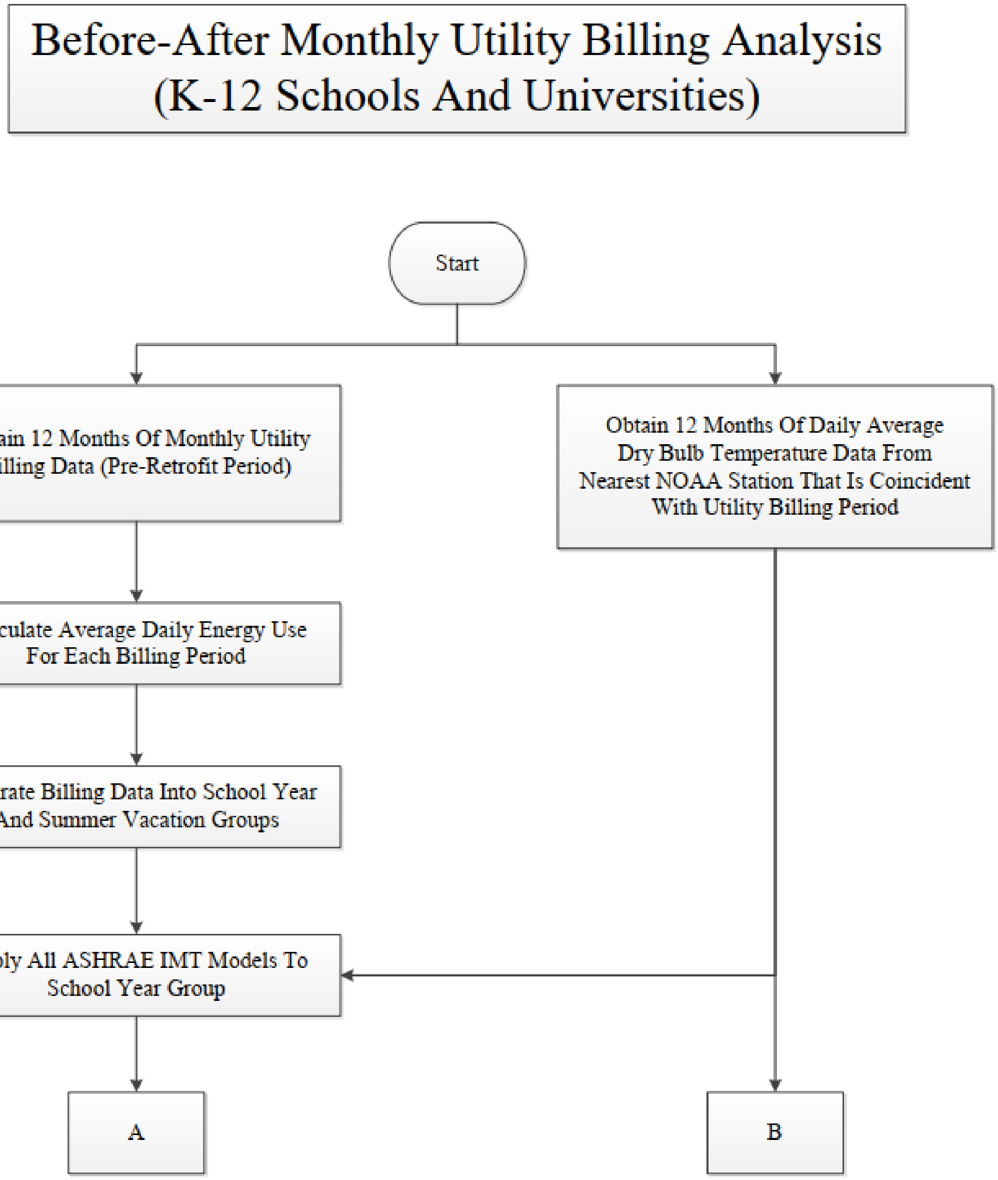


Figure 13: Before-After Monthly Utility Billing Analysis (K-12 Schools & Universities)

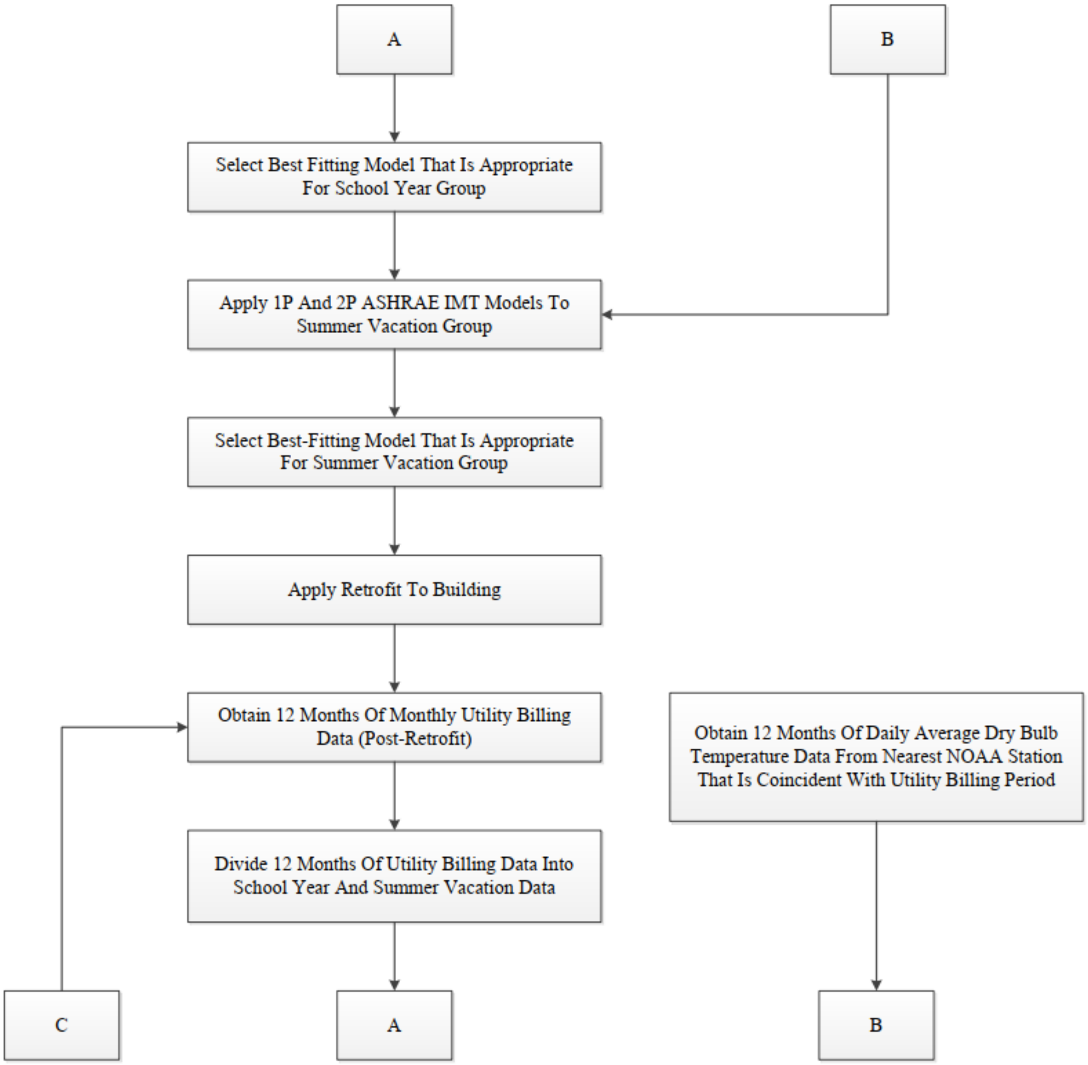


Figure 13 : Before-After Monthly Utility Billing Analysis (K-12 Schools & Universities) (cont).

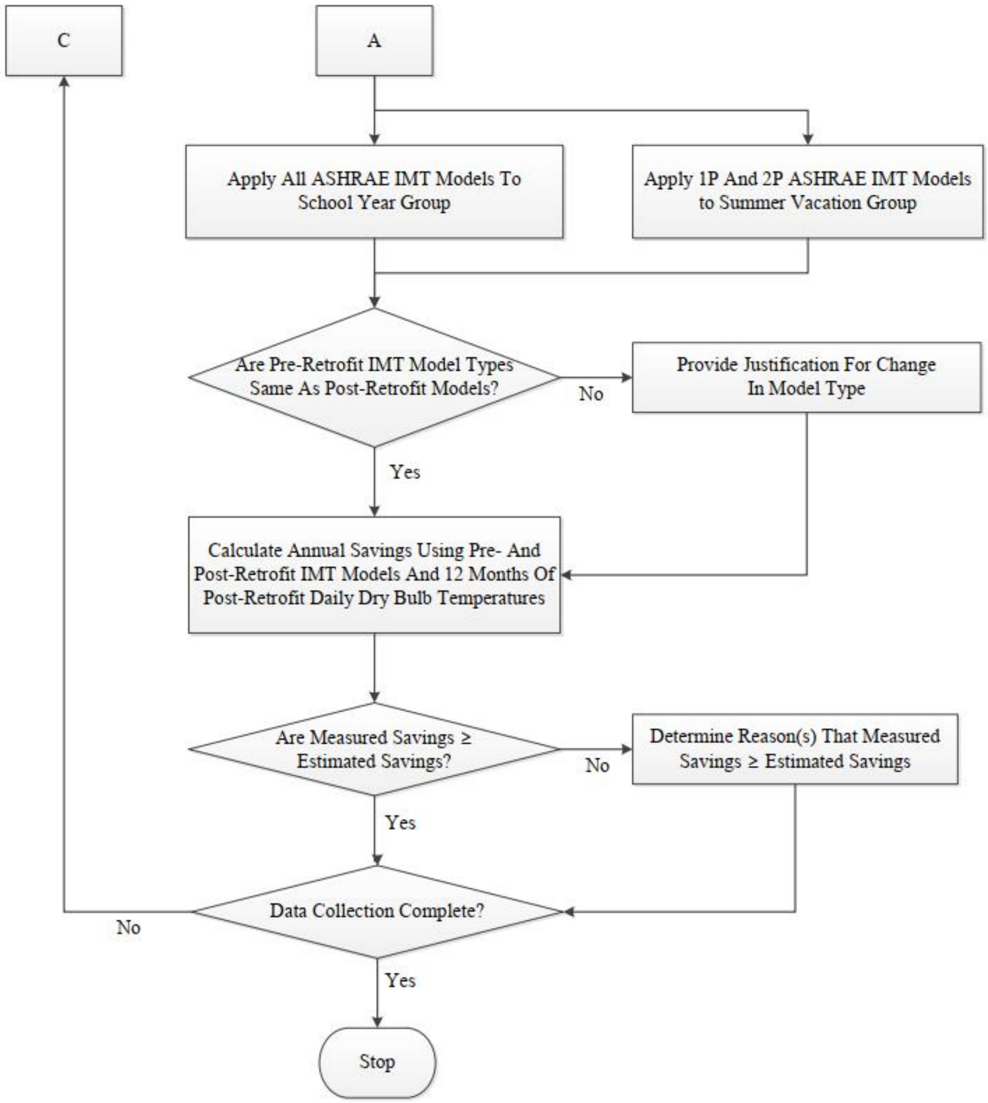


Figure 13: Before-After Monthly Utility Billing Analysis (K-12 Schools & Universities) (cont).

1.11 ASHRAE'S INVERSE MODEL TOOLKIT (IMT)

ASHRAE's Inverse Modeling Toolkit (IMT) is a FORTRAN 90 application for calculating linear, change-point linear, variable-based degree days, multilinear and combined regression models. The development of the IMT was sponsored by ASHRAE Technical Committee TC 4.7 – Energy Calculations. The ASHRAE IMT is public domain software that can be obtained from ASHRAE https://www.ashrae.org/technical-resources/free-resources/software.

Two papers were written for the ASHRAE Transactions including Kissock et al. (2002) "Inverse Modeling Toolkit: Numerical Algorithms, and Haberl et al. (2002), "Inverse Model Toolkit (1050RP): Application and Testing". Currently, TC 4.7 is proposing to update the IMT to be more compliant with today's software, API, etc.

- The ASHRAE Inverse Modeling Toolkit (IMT) contains:
- A final Report;
- A User's Manual;
- Software Requirement Specifications (SRS);
- Software; and example input/output files.

The ASHRAE IMT is provided in two (2) zip folders:

- ASHRAE-RP-1050-Final-Report
- ASHRAE-RP-1050-Toolkit

The ASHRAE RP-1050-Final-Report has all the documentation for the project as shown in Figure 14.

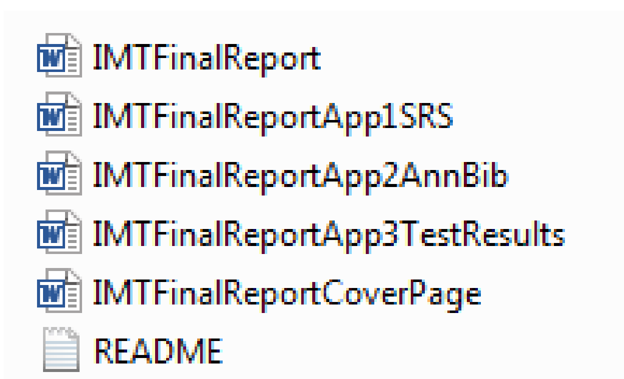


Figure 14: Contents of the ASHRAE RP-1050 Final Report.

The ASHRAE IMT contains the Inverse Model Toolkit, including: Source code, executable, sample input files, etc.

DAILY2.DAT	DAT File	9 KB	No
daily2ins	Text Document	1 KB	No
FTN90.DLL	Application extension	117 KB	No
imt19	Application	45 KB	No
imt19.f90	F90 File	20 KB	No
InverseModelToolkitD1	Microsoft Word 97 - 2003 ...	1,336 KB	No
NONUNIPP.DAT	DAT File	3 KB	No
nonunippins	Text Document	1 KB	No
README	Text Document	1 KB	No
SALFLIBC.DLL	Application extension	502 KB	No

Figure 15: ASHRAE IMT Software files.

ASHRAE IMT Sample Files:

The ASHRAE IMT comes with two (2) sample files: the DAILY2.DAT file and the NONUNIPP.DAT file. The DAILY2.DAT contains daily ambient temperatures and energy consumption data from a commercial building in Texas. The DAILY2.DAT is used to demonstrate 2P, 3P, 4P, 5P and MVR models.

The second example file is a non-uniform timescale data file called NONUNIPP.DAT. NONUNIPP.DAT contains monthly energy use and occupancy data, and daily ambient temperatures. The NONUNIPP.DAT can be used to run variable based degree day models and for calculating average billing period temperatures.

- To calculate the average billing period temperature:
- First monthly energy use and daily temperatures are entered into a format that complies with NONUNIPP.DAT
- Next the IMT is then run to calculate CDD or HDD values, and the average billing period temperature.
- The residual file from the NONUNIPP.DAT can then used by IMT to calculate mean, 2P, 3P, 4P, 5P and MVR models (second pass).

Running the Sample Input Data File: DAILY2.DAT

The DAILY2.DAT is a uniform time-scale data file containing daily ambient temperatures and energy consumption data from a commercial building. The fields are:

Line 1: Site number

Line 2: Month

Line 3: Day

Line 4: Year

Line 5: Group field (1 for pre-retrofit period and 2 for post-retrofit period)

Line 6: Cooling energy use (MBtu/day)

Line 7: Heating energy use (MBtu/day)

Line 8: Whole building electricity use (kWh/day)

Line 9: Average ambient temperature (F)

DAILY2INS.TXT is a file that gives IMT instructions to generate a multivariable regression (MVR) model of cooling energy use as a function of building electricity use and ambient temperature. DAILY2.DAT contains the following data…

Col: 1	2	3	4	5	6	7	8	9
SITE	MO	DAY	YEAR	GROUP	COOL	HEAT	ELEC	TEMP
114	10	16	90	1	61.8	27.23	-99	76
114	10	17	90	1	65.2	25.68	-99	79
114	10	18	90	1	44.2	35.21	-99	64
114	10	19	90	1	42.6	38.66	-99	62
114	10	20	90	1	52	32.76	-99	70
114	10	21	90	1	44.8	41.29	-99	63
114	10	22	90	1	36.8	44.2	-99	57
114	10	23	90	1	-99	-99	-99	58
114	10	24	90	1	41	39.66	-99	63
114	10	25	90	1	41.8	37.66	-99	64
114	10	26	90	1	43.2	37.39	-99	62
114	10	27	90	1	45.2	33.49	-99	65
114	10	28	90	1	46.8	32.49	-99	68

Figure 16: Partial Contents of the DAILY2.DAT file.

```
Line 1: Path and name of input data file = daily2.dat
Line 2: Value of no data flag = -99
Line 3: Column number of group field = 5
Line 4: Value of valid group field = 1
Line 5: Residual file needed (1 yes, 0 no) = 1
Line 6: Model (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 7
Line 7: Column number of dependent variable = 6
Line 8: Number of Y1 independent variables data file (0 to 6) = 2
Line 9: Column number of X1 independent variable = 8
Line 10: Column number of X2 independent variable = 9
Line 11: Column number of X3 independent variable = 0
Line 12: Column number of X4 independent variable = 0
Line 13: Column number of X5 independent variable = 0
Line 14: Column number of X6 independent variable = 0
```

Figure 17: DAILY2INS.TXT instruction file to generate a multivariable regression (MVR) model of cooling energy use as a function of building electricity use and ambient temperature.

Line 1: enter the path and name of the data-input file. If the data-input file is in the same folder as IMT.EXE, the path need not be entered (daily2.dat).

Line 2: enter the value of the marker, called the 'no-data flag', used to denote missing data. A typical value for the no-data flag is '–99'. IMT will not use data from the data-input file in regression models if the data has the value of the no-data flag specified on Line 2. (-99)

Line 3: enter the column number of the grouping field in the data-input file. The grouping field is an optional column in the data-input file for indicating which records should be included in the IMT regression model. If the data-input file does not have a grouping field, enter '0'. Entering '0' on Line 3 causes IMT to use all of the data in the input-data file in the regression model. (5)

Line 4: enter the value of the data in the grouping field that indicates that this record should be included in the regression model. For example, if the data-input file includes data from both the pre-retrofit and post-retrofit periods, a grouping field could be added to the data-input file with a value of '1' for each pre-retrofit record and a value of '2' for each post-retrofit record. The column number of this field in the data-input file should be entered in the instruction file on Line 3. To develop a regression model of pre-retrofit data, enter '1' on Line 4 of the instruction file. To develop a regression model of post-retrofit data, enter '2' on Line 4 of the instruction file. (1)

Line 5: enter '1' if a residual output file, IMT.RES, is desired and "0" if no residual output file is desired. Residual output files are described in more detail in Chapter 7 of IMT Final Report. (1)

Line 6: enter the number 1 through 9 corresponding to the desired regression model. IMT regression models are described in more detail in Chapter 5 (IMT Final Report). (7)

Line 7: enter the column number in the data-input file of the dependent variable. For example, to create a model of chiller energy use as a function of outdoor air temperature, chiller energy use would be the dependent variable and outdoor-air temperature would be the independent variable. (6)

Line 8: enter the number of independent variables to be used in the model. For example, to create a model of chiller energy use as a function of outdoor-air temperature and outdoor-air specific humidity, the number of independent variables would be ‘2’. (2)

Lines 9-14: enter the column number(s) in the data-input file of the independent variable(s). Enter ‘0’ for all unused independent variables. (X1 = 8, X2 = 9)

Running the Sample Input Data File: DAILY2.DAT

Running the daily2ins.txt file produces the following ASCII output.

N = number of data points

R2 = coeff of multiple determination

AdjR2 = adjusted R2

RMSE = Root mean squared error

CV-RMSE = Coefficient of variation for the RMSE

P = auto-correlation coeff.

DW = Durbin Watson coefficient

a = constant intercept

X1 = left-hand slope

X2 = right-hand slope

```
********************************************
 ASHRAE INVERSE MODELING TOOLKIT (1.9)
********************************************
   Output file name = IMT.Out
********************************************
   Input data file name =  daily2.dat
   Model type =           MVR
   Grouping column No =    5
   Value for grouping =    1
   Residual mode =         1
   # of X(Indep.) Var =    2
   Y1 column number =      6
   X1 column number =   8
   X2 column number =   9
   X3 column number =   0 (unused)
   X4 column number =   0 (unused)
   X5 column number =   0 (unused)
   X6 column number =   0 (unused)
********************************************
   Regression Results
  --------------------------------------
          N =    167
  --------------------------------------
         R2 =     0.845
  --------------------------------------
      AdjR2 =     0.845
  --------------------------------------
       RMSE =      6.4314
  --------------------------------------
    CV-RMSE =    11.328%
  --------------------------------------
          p =     0.627
  --------------------------------------
         DW =     0.740 (p>0)
  --------------------------------------
          a =    -50.6026 (      5.8082)
  --------------------------------------
         X1 =      0.0035 (      0.0007)
  --------------------------------------
         X2 =      1.2576 (      0.0421)
  --------------------------------------
```

Figure 18: Output file from the IMT produced by the DAILY2INS.TXT instruction file.

Running the Sample Input Data File: NONUNIPP.DAT

The IMT also has a special data input format to facilitate the calculation of Variable-Based Degree-Days (VBDD) for analyzing monthly utilility bills and daily energy use (i.e., a common problem).

NONUNIPP.DAT and NONUNIPP.TXT are the two files that are used for analyzing monthly utility bills with daily temperature data (Figure 19). The NONUNIPP.DAT and NONUNIPP.TXT files can be edited with a text editor, or it can be imported into MS EXCEL for analysis or plotting by spreadsheet.

MO	DY	YR	COOL	GROUP	DUM1	D2	D3	TEMP
12	1	1996	-99	-99	-99	-99	-99	26
12	2	1996	-99	-99	-99	-99	-99	36
12	3	1996	-99	-99	-99	-99	-99	38
12	4	1996	-99	-99	-99	-99	-99	31
12	5	1996	-99	-99	-99	-99	-99	32
12	6	1996	-99	-99	-99	-99	-99	36
12	7	1996	-99	-99	-99	-99	-99	40
12	8	1996	-99	-99	-99	-99	-99	32
12	9	1996	-99	-99	-99	-99	-99	30
12	10	1996	-99	-99	-99	-99	-99	41
12	11	1996	-99	-99	-99	-99	-99	56
12	12	1996	-99	-99	-99	-99	-99	42
12	13	1996	-99	-99	-99	-99	-99	38
12	14	1996	-99	-99	-99	-99	-99	37
12	15	1996	-99	-99	-99	-99	-99	43
12	16	1996	-99	-99	-99	-99	-99	38
12	17	1996	-99	-99	-99	-99	-99	36
12	18	1996	-99	-99	-99	-99	-99	22
12	19	1996	-99	-99	-99	-99	-99	13
12	20	1996	-99	-99	-99	-99	-99	-99
12	21	1996	-99	-99	-99	-99	-99	-99
12	22	1996	-99	-99	-99	-99	-99	-99
12	23	1996	-99	-99	-99	-99	-99	45
12	24	1996	-99	-99	-99	-99	-99	43
12	25	1996	-99	-99	-99	-99	-99	22
12	26	1996	-99	-99	-99	-99	-99	29
12	27	1996	-99	-99	-99	-99	-99	37
12	28	1996	-99	-99	-99	-99	-99	52
12	29	1996	-99	-99	-99	-99	-99	50
12	30	1996	-99	-99	-99	-99	-99	-99
12	31	1996	-99	-99	-99	-99	-99	44
1	1	1997	215	1	30	20	5	41
1	2	1997	-99	-99	-99	-99	-99	52
1	3	1997	-99	-99	-99	-99	-99	57
1	4	1997	-99	-99	-99	-99	-99	60
1	5	1997	-99	-99	-99	-99	-99	47
1	6	1997	-99	-99	-99	-99	-99	25

Figure 19: Portion of the NONUNIPP.DAT file.

Running the Sample Input Data File: NONUNIPP.DAT

The NONUNIPP.DAT file contains monthly utility data in columns 4 through 8 and daily temperatures in column 9. The NONUNIPP can be used to calculate: VBDD or average billing period temperatures.

Running the Sample Input Data File: NONUNIPP.DAT

The NONUNIPP.TXT file contains instructions for running the NONUNIPP.DAT file. It contains the commands for running NONUNIPP type files:

```
Line 1: Path and name of input data file = nonunipp.dat
Line 2: Value of no-data flag = -99
Line 3: Column number of group field = 5
Line 4: Value of valid group field = 1
Line 5: Residual file needed (1 yes, 0 no) = 1
Line 6: Model
(1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 9
Line 7: Column number of dependent variable Y = 4
Line 8: Number of independent variables (0 to 6)  = 1
Line 9: Column number of independent variable X1 = 9
Line 10: Column number of independent variable X2 = 0
Line 11: Column number of independent variable X3 = 0
Line 12: Column number of independent variable X4 = 0
Line 13: Column number of independent variable X5 = 0
Line 14: Column number of independent variable X6 = 0
```

Figure 20: Contents of the NONUNIPPINS.TXT instruction file.

The NONUNIPP.DAT contains:

Column 1: Month

Column 2: Day

Column 3: Year

Column 4: Cooling energy use (units/month)

Column 5: Group field (1 for pre-retrofit period and 2 for post-retrofit period)

Column 6: Independent variable 1

Column 7: Independent variable 2

Column 8: Independent variable 3

Column 9: Average daily ambient temperature (F)

The NONUNIPPINS.TXT generates the following output file

```
Reading instruction file...
Reading data file...
Filling X<> and Y<>...
Running VBDD model...
Creating IMT.OUT and IMT.RES ...


********************************************
 ASHRAE INVERSE MODELING TOOLKIT <1.9>
********************************************
   Output file name = IMT.Out
********************************************
   Input data file name =  nonunipp.dat
   Model type =           CDD
   Grouping column No =     5
   Value for grouping =     1
   Residual mode =          1
   # of X<Indep.> Var =     1
   Y1 column number =       4
   X1 column number =   9
   X2 column number =   0 <unused>
   X3 column number =   0 <unused>
   X4 column number =   0 <unused>
   X5 column number =   0 <unused>
   X6 column number =   0 <unused>
********************************************
   Regression Results
  --------------------------------------
          N =     12
  --------------------------------------
         R2 =     0.810
  --------------------------------------
      AdjR2 =     0.810
  --------------------------------------
       RMSE =     34.4537
  --------------------------------------
    CV-RMSE =    10.313%
  --------------------------------------
          p =     0.493
  --------------------------------------
         DW =     0.854 <p>0>
  --------------------------------------
   DD Base =      41
  --------------------------------------
          A =  258.0816 <     15.3174>
  --------------------------------------
         X1 =    0.1993 <      0.0305>
  --------------------------------------
```

Figure 21: Example output file generated by the NONUNIPPINS.TXT file.

IMT also creates a residual file as shown in Figure 22. The residual file repeats the input file and adds:

- average temperature (col 10)
- the predicted use and (col 11)
- the difference (col 12)

The NONUNIPP.DAT contains (i.e., first 9 columns):

Column 1: Month

Column 2: Day

Column 3: Year

Column 4: Cooling energy use (units/month)

Column 5: Group field (1 for pre-retrofit period and 2 for post-retrofit period)

Column 6: Independent variable 1

Column 7: Independent variable 2

Column 8: Independent variable 3

Column 9: Average daily ambient temperature

Column 10: CDD

Column 11: Predicted cooling energy use

Column 12: Difference

Col 1	2	3	4	5	6	7	8	9	10	11	12
2.00	1.00	1997.00	268.00	1.00	35.00	30.00	3.00	26.03	58.00	269.64	-1.64
3.00	1.00	1997.00	270.00	1.00	40.00	25.00	-5.00	40.00	76.00	273.23	-3.23
4.00	1.00	1997.00	321.00	1.00	45.00	30.00	6.00	42.48	88.00	275.62	45.38
5.00	1.00	1997.00	357.00	1.00	55.00	30.00	-8.00	48.69	231.00	304.11	52.89
6.00	1.00	1997.00	367.00	1.00	65.00	15.00	-3.00	57.26	504.00	358.51	8.49
7.00	1.00	1997.00	435.00	1.00	75.00	20.00	0.00	69.52	770.00	411.51	23.49
8.00	1.00	1997.00	447.00	1.00	75.00	20.00	12.00	73.71	785.00	414.50	32.50
9.00	1.00	1997.00	396.00	1.00	65.00	25.00	-4.00	70.43	883.00	434.03	-38.03
10.00	1.00	1997.00	373.00	1.00	55.00	30.00	8.00	64.93	718.00	401.15	-28.15
11.00	1.00	1997.00	324.00	1.00	45.00	30.00	9.00	54.61	435.00	344.76	-20.76
12.00	1.00	1997.00	235.00	1.00	35.00	25.00	-15.00	36.94	21.00	262.27	-27.27
1.00	1.00	1998.00	216.00	1.00	30.00	20.00	6.00	33.30	8.00	259.68	-43.68

Figure 22: Residual file produce by the NONUNIPPINS.TXT instruction file.

In the example shown in Figure 21, Column 9 contains the average billing period temperature for the monthly utility use of the example building contained in the NONUNIPP.DAT file.

1.12 POLLUTANT AND GREEN HOUSE GAS COST SAVINGS

Pollutant and Green House Gas Cost Savings. All projects shall meet or exceed any applicable federal or state air pollution rule or regulation. Because these rules can be complex, it is recommended the applicant verify which rules are applicable by contacting either the Ohio EPA or by utilizing an experience air pollution consultant.

For projects that exceed federal or state air pollution or energy efficiency standards, the OAQDA recognizes the importance of reduced air pollution. A review of similar grant projects in the U.S. is summarized in Figure 23. These values as proposed as a general guide for pricing the value of NOx, SOx, CO2 or PM reductions. In general, Total M&V costs should not exceed 10% of project cost or 5% of project savings.

Item	Incentive Grants (total/project)	Reference
NOx	$5.40/lb-NOx	TCEQ 2019
SOx	$2.21/lb-SOx	RECLAIM 2020
CO2	$0.018/lb-CO2	NACP 2009
PM	$20k to $250k/proj. or $11 to $105/ton	P2 2020

Figure 23: Reference Costs for Mitigating NOx, SOx, CO2 and PM

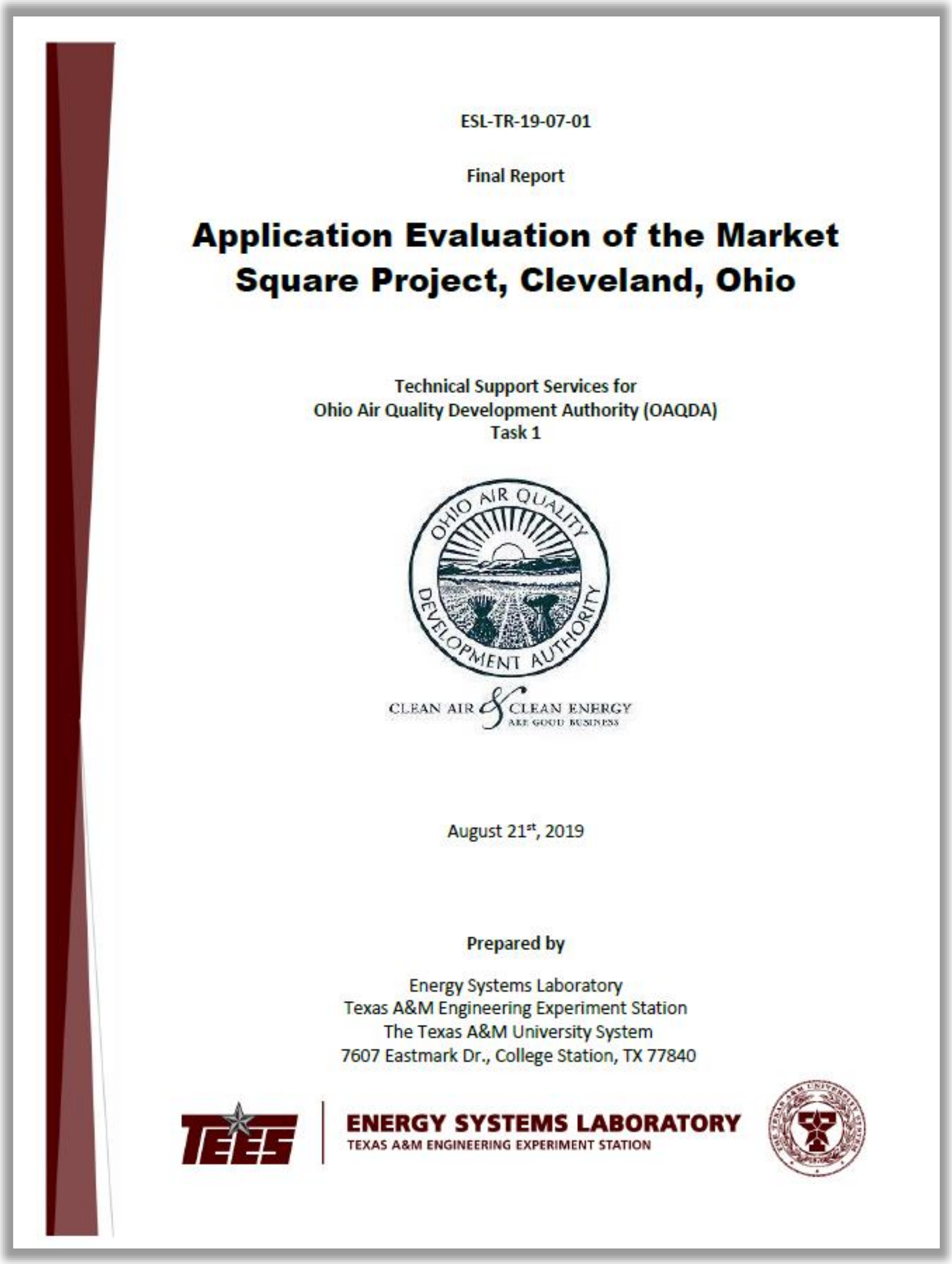
Example: Application Evaluation of the Market Square Project, Cleveland, Ohio

In this next section, an example of M&V costs is provides using the Market Square Project evaluation that was previously developed for the OAQDA (ESL 2019). Figure 24 shows the cover page of the OAQDA report, which includes the material regarding the NOx, SOx, CO2 and PM reductions from the proposed project, and Figure 25 shows the Executive Summary of the report that contains the proposed energy use reductions and reduced air pollution values for use in this example.

In summary, the analysis showed the Market Square Project was projected to save the following:

Total electricity savings of 2,353,255 kWh (includes grid losses = 4.9%), Total natural gas savings of 4,085 MMBtu (includes pipeline losses = 5%), Total cost savings of $332,893 per year, which include: Total electricity savings of $300,606 per year, Total natural gas savings of $32,287 per year.

Total annual emissions reduction of: Total NOx reductions of 2,127 lbs (electric + natural gas) per year, Total SO2 reductions of 2,826 lbs (electric + natural gas) per year, Total CO2 reductions of 3,399,140 lbs (electric + natural gas) per year.



ESL-TR-19-07-01

Final Report

Application Evaluation of the Market Square Project, Cleveland, Ohio

Technical Support Services for
Ohio Air Quality Development Authority (OAQDA)
Task 1

OHIO AIR QUALITY DEVELOPMENT AUTHORITY

CLEAN AIR & CLEAN ENERGY ARE GOOD BUSINESS

August 21st, 2019

Prepared by

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Figure 24: ESL Report: Application Evaluation of the Market Square Project, Cleveland, Ohio.

EXECUTIVE SUMMARY

This report for Technical Support Services: Task 1. Application Evaluation of the Market Square Project, Cleveland, Ohio, summarizes the technical analysis performed on the materials provided that estimate the emissions reduction for the energy efficient design of the Market Square Project in Cleveland, Ohio. This technical analysis evaluates the technical merits of the project proposal to conserve air as a natural resource by preventing air pollution from electric power production from fossil fuel combustion in Ohio and from on-site combustion of natural gas. The analysis is based on project application materials received from Dunham Engineering consisting of an overall project description and input/out files from the EQUEST 3.65 whole-building simulation program used to calculate the electricity and natural gas use.

To perform the analysis for Task 1 the following sub-tasks were completed:

- Task 1.1: Receive and review project application materials, including construction drawings, calculations, and other documents.
- Task 1.2: Analysis of the energy code compliance with ASHRAE Standard 90.1-2010.
- Task 1.3: Analysis of the simulated electricity and natural gas savings from the Office and Apartment buildings at Market Square, including calculation of key whole-building energy use metrics for the project.
- Task 1.4: Calculation of the 40 to 60 kW PV installation.
- Task 1.5: Analysis of air pollution savings from electricity and natural gas savings from the energy efficient design of the Office and Apartment buildings at the Market Square Project in Cleveland, Ohio.
- Task 1.6: Identification of limitations and risks that may occur during construction and operation of the project that may adversely impact the expected benefits to the State in energy savings and emissions reductions.

In summary, this analysis has verified the total annual energy savings of:

- Total electricity savings of 2,353,255 kWh (includes grid losses = 4.9%),
- Total natural gas savings of 4,085 MMBtu (includes pipeline losses = 5%),
- Total cost savings of $332,893 per year, which include:
- Total electricity savings of $300,606 per year,
- Total natural gas savings of $32,287 per year.

As well as total annual emissions reduction of:

- Total NOx reductions of 2,127 lbs (electric + natural gas) per year,
- Total SO2 reductions of 2,826 lbs (electric + natural gas) per year,
- Total CO2 reductions of 3,399,140 lbs (electric + natural gas) per year.

These savings represent the calculated annual energy savings and resultant annual emissions reduction for the intended operation of the proposed project to serve as an Air Quality Facility as defined in Chapter 3706 of the Ohio revised code.

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Figure 25: Executive Summary of the OAQDA Market Square Report.

This analysis has identified the following Energy Conservation Design Measures (ECDMs) as contributing significantly to reducing the overall annual energy use:

- The use of energy efficient windows,
- The use of an Energy Recovery Ventilator (ERV) for exhaust air,
- Improved boiler and chiller efficiencies,
- Improved interior and exterior lighting,
- Shading of the Office building,
- Improved insulation levels (walls, ceiling and floors),
- Improved ventilation system (parking),
- The use of thermal mass (i.e., concrete, steel & timber).

	Annual Consumption of Office, Retail, Apts, Parking & Lighting		
	Electric Consumption (kWh, site+grid)	Natural Gas Consumption (MMBtu,site+p.loss)	Total Energy Consumption (MMBtu)
Energy Code Complaint Baseline	5,987,068	9,233	29,666
Proposed	3,633,814	5,149	17,551
Savings	2,353,255	4,085	12,115
% Savings	39%	44%	41%

	Annual Emissions of Office, Retail, Apts, Parking & Lighting		
	Nitrous Oxide (NOx) Emissions (lbs)	Sulfur Dioxide (SO2) Emissions (lbs)	CO2 Emissions (lbs)
Energy Code Complaint Baseline	5,408	7,188	8,513,832
Proposed	3,281	4,364	5,114,692
Savings	2,127	2,826	3,399,140
% Savings	39%	39%	40%

Total Energy Savings and Emissions Reductions from the proposed Market Square Project

The calculated savings do not include the electricity production from on-site renewable energy systems based on the project application materials submitted to date. Calculation of the electric demand was not included in this project.

Finally, the calculated savings do not include energy savings associated with the embodied energy use representative of the materials used in the project (i.e., timber). Where the "Embodied energy use is sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself" (Source" www.wikipedia.org, 2019).

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Figure 25: Executive Summary of the OAQDA Market Square Report (cont).

Applying the reference costs for mitigating NOx, SOx, CO2 and PM (Figure 23), yields the air pollution reduction estimates (Figure 26).

ELECTRICITY SAVINGS	**$/year**	(Includes 4.9% grid loss)	
2,353,255 kWh/yr	$300,606		
2,353 MWh/yr			
NATURAL GAS SAVINGS	**$/year**	(includes 5% pipeline loss)	
4,085 MMBtu/yr	$32,287		
TOTAL (Electricity + Nat. Gas)	**$/year**	**(**excludes electric demand)	
	$332,893		
TOTAL ANNUAL EMISSIONS REDUCTIONS		**(**electric + nat.gas) per year	
NOx (lbs)	SOx (lbs)	CO2 (lbs)	
2,127	2,826	3,339,140	
NOx ($/lb-NOx)	SOx ($/lb-SOx)	CO2 ($/lb-CO2)	
$5.40	$2.21	$0.018	
NOx ($/yr)	SOx ($/yr)	CO2 ($/yr)	Total ($/yr)
$11,486	$6,245	$60,105	$77,836

Figure 26: Example Air Pollution Calculation of Market Square Project Using Reference Costs

These calculations show that the estimated Market Square Project electricity savings of 2,353,255 kWh/yr ($300,606) and natural gas savings of 4,085 MMBtu/yr ($32,287) would have yielded: 2,127 lbs (NOx) reductions, 2,826 lbs (SOx) reductions and 3,339,140 lbs (CO2) reductions, which can be valued at $11,486 (NOx), $6,245 (SOx) and $60,105 (CO2) using the reference costs (Figure 23).

Choosing the Appropriate Level of M&V for Different Projects

Figure 27 provides information about how the project size and complexity determine the value and extent of the Measurement and Verification (M&V) required over the project period. In the figure whole-building project (calibrated simulation, before/after), and component isolation projects (new, retrofit, renewable, criteria pollutant) are listed along one axis versus the project size on the opposite axis.

A maximum M&V value of 10% of the total project cost is then used to value the Measurement and Verification (M&V), using Small (Cost: $0 to $100,000), Medium (Cost: $100,001 to $500,000), Large (Cost: $500,001 to $1,000,000) and Very Large (Cost: $1,000,001 to $100,000,000+). This M&V cost is intended to cover the cost of a an independent third party M&V firm, and staff cost(s) at OAQDA to manage the independent M&V and project database (ASHRAE 2014).

	Small Project Cost: $0 to $100,000	Medium Project Cost: $100,001 to $500,000	Large Project Cost: $500,001 to $1,000,000	Very Large Project Cost: $1,000,001 to $100,000,000+
MEASUREMENT METHOD	M&V Value: None to $10,000	M&V Value: $10,000 to $50,000	M&V Value: $50,000 to $100,000	M&V Value:$100,000 to $10,000,000
Whole-Building (new) Calibrated Simulation		XXXX	XXXX	XXXX
Whole-Building (retrofit) Before/After (Interval data)		XXXX	XXXX	XXXX
Whole-Building (retrofit) Before/After (12 months)	XXXX	XXXX		
Whole-Building (new) Before/After (12 mo. Seasonal)	XXXX	XXXX		
Component Isolation (new)	XXXX	XXXX	XXXX	XXXX
Component Isolation (retrofit)	XXXX	XXXX	XXXX	XXXX
Component Isolation (renewable)	XXXX	XXXX	XXXX	XXXX
Component Isolation (new) Criteria Pollutant	XXXX	XXXX	XXXX	XXXX
Component Isolation (retrofit) Criteria Pollutant	XXXX	XXXX	XXXX	XXXX

Note: 1) M&V Valued at 10% of total project cost.

Figure 27: Measurement Method Guideline for Whole-Building and Component Isolation projects of varying sizes.

Example M&V cost.

Whole-building Calibrated Simulation (new). For a whole-building calibrated simulation that was valued at $250,000, OAQDA would value the M&V for the project at $25,000, which represents 10% of the total project costs. This M&V cost would need to cover:

- Review of the project application.
- Review of the M&V plan, commissioning plan and construction.
- Review of the data collection following post construction.
- Determination of annual savings over the project period.
- Archiving of all data from the project over the full project term.

2.0 GLOSSARY

Air Quality Facility	Pursuant to Ohio Revised Code 3706.01, Air Quality Facility means any of the following: (1) Any method, modification or replacement of property, process, device, structure, or equipment that removes, reduces, prevents, contains, alters, conveys, stores, disperses, or disposes of air contaminants or substances containing air contaminants, or that renders less noxious or reduces the concentration of air contaminants in the ambient air, including, without limitation, facilities and expenditures that qualify as air pollution control facilities under section 103 (C)(4)(F) of the Internal Revenue Code of 1954, as amended, and regulations adopted thereunder; (2) Motor vehicle inspection stations operated in accordance with, and any equipment used for motor vehicle inspections conducted under, section 3704.14 of the Revised Code and rules adopted under it; (3) Ethanol or other biofuel facilities, including any equipment used at the ethanol or other biofuel facility for the production of ethanol or other biofuels; (4) Any property or portion thereof used for the collection, storage, treatment, utilization, processing, or final disposal of a by-product or solid waste resulting from any method, process, device, structure, or equipment that removes, reduces, prevents, contains, alters, conveys, stores, disperses, or disposes of air contaminants, or that renders less noxious or reduces the concentration of air contaminants in the ambient air; (5) Any property, device, or equipment that promotes the reduction of emissions of air contaminants into the ambient air through improvements in the efficiency of energy utilization or energy conservation; (6) Any coal research and development project conducted under Chapter 1555. of the Revised Code; (7) As determined by the director of the Ohio coal development office, any property or portion thereof that is used for the collection, storage, treatment, utilization, processing, or final disposal of a by-product resulting from a coal research and development project as defined in section 1555.01 of the Revised Code or from the use of clean coal technology, excluding any property or portion thereof that is used primarily for other subsequent commercial purposes; (8) Any property or portion thereof that is part of the FutureGen project of the United States department of energy or related to the siting of the FutureGen project; (9) Any property, device, or equipment that promotes the

reduction of emissions of air contaminants into the ambient air through the generation of clean, renewable energy with renewable energy resources or advanced energy resources as defined in section 3706.25 of the Revised Code; (10) Any property, device, structure or equipment necessary for the manufacture and production of equipment described as an air quality facility under this chapter; (11) Any property, device, or equipment related to the recharging or refueling of vehicles that promotes the reduction of emissions of air contaminants into the ambient air through the use of an alternative fuel as defined in section 125.831 of the Revised Code or the use of a renewable energy resource as defined in section 3706.25 of the Revised Code. "Air quality facility" further includes any property or system to be used in whole or in part for any of the purposes in divisions (G)(1) to (11) of this section, whether another purpose is also served, and any property or system incidental to or that has to do with, or the end purpose of which is, any of the foregoing. Air quality facilities that are defined in this division for industry, commerce, distribution, or research, including public utility companies, are hereby determined to be those that qualify as facilities for the control of air pollution and thermal pollution related to air under Section 13 of Article VIII, Ohio Constitution.

Application (Pre & Full) See Appendix A for the Complete Application. Interested applicants with simple projects may submit a completed application for OAQDA evaluation. Applicants with complex projects, new construction, major rehab or repurposing are encouraged to submit a Pre-Application with the preliminary project scope, prior to full engineering or costing. This Pre-Application will be used to initiate a dialogue with OAQDA staff for the preliminary approval of qualified components, in order to provide applicants with an understanding of additional information that will be required for a Full Application approval.

ASHRAE American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, GA.

CO2 Carbon dioxide (chemical formula CO2) is a colorless gas with a density about 60% higher than that of dry air. Carbon dioxide consists of a carbon atom covalently double bonded to two oxygen atoms. It occurs naturally in Earth's atmosphere as a trace gas. The current concentration is about 0.04% (412 ppm) by volume, having risen from pre-industrial levels of 280 ppm.

Component Isolation Savings measurement approach defined by ASHRAE Guideline 14 that determines energy savings for a specific building system. Component isolation is performed using energy measurements to isolate the energy flows for the specific system(s) under consideration.

Conduit Bond Issuer	OAQDA is authorized to issue bonds in order to provide funds to approved applicants, subject to these Guidelines. Bond repayment is the responsibility of the underlying applicant, with no recourse to OAQDA. OAQDA provides access to the bond market in this "conduit" role, in addition to the potential tax exemptions as described herein.
Energy Conservation Design Measure (ECDM)	Savings measurement approach defined by ASHRAE Guideline 14 that determines energy savings for a specific building system. Component isolation is performed using energy measurements to isolate the energy flows for the specific system(s) under consideration.
Green Bonds	Label available to bond issuers to signal investors that proceeds will be used for purposes that contribute the environmental benefit of the project location and/or operations.
Monitoring & Verification (M&V)	Monitoring & Verification (M&V) is the determination of actual energy savings achieved by one or more energy conservation measure(s). Savings cannot be directly measured because they represent the absence of energy use. Instead, actual savings are determined by comparing measured use before and after implementation of a project and making appropriate adjustments for changes in conditions.
NOx	In atmospheric chemistry, NOx is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO2). These gases contribute to the formation of smog and acid rain, as well as affecting tropospheric ozone.
Particulate Matter (PM)	Particulate Matter (PM) describes solids and/or liquid particles suspended in the atmosphere.
Real Property Tax	Property taxes on real property. This includes taxes for land, improvements, and, depending on location, other specifically authorized charged of the local taxing authorities.
Sales and Use Tax	Taxes associated with the purchase and use of materials and equipment for construction, retrofitting, rehabilitation, repurposing of a building.
Sox	Sulfur oxide (SOx) refers to one or more of the following: Lower sulfur oxides, Sulfur monoxide (SO), Disulfur dioxide (S2O2), Sulfur dioxide (SO2), Sulfur trioxide (SO3), Higher sulfur oxides (SO3 and SO4), and Disulfur monoxide (S2O)
Tax Exemption	[PLACEHOLDER]

Whole Building Energy savings measurement approach defined in ASHRAE Guideline 14 that determines
energy and demand savings through the use of whole-facility energy (end-use) data, which may be measured by utility meters or data loggers.

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